Developing Specifications for Using Recycled Asphalt Pavement as Base, Subbase or General Fill Materials,

Phase II

Final Report

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15. Supplementary Notes

This Phase II work focused on 1) validating the Phase I developmental specifications for using Recycled Asphalt Pavement (RAP) as a base, sub-base or general fill, 2) evaluating the strength gain of RAP within the first two months after construction, 3) evaluating RAP-Soil mixes in the laboratory and 4) evaluating the environmental performance of RAP in the field.

The Phase I Developmental Specifications were updated to allow RAP as a sub-base below rigid pavements. A second field site was constructed using RAP and a Limerock control section. It included surface water and leachate water collection systems in both the RAP and Limerock. The initial strength gains were evaluated over an 8-week period and the environmental performance was analyzed over 12-months. Construction with RAP was equivalent to or better than construction with Limerock.

RAP's strength-deformation behavior increased throughout the 8-week study period based on Field California Bearing Ratio (CBR) data converted to Limerock Bearing Ratio (LBR), Initial Stiffness Modulus (ISM) values from the Falling Weight Deflectometer (FWD), and stiffness values from both the Clegg Impact Hammer and the Soil Stiffness Gage (SSG). LBR, Clegg and ISM data indicated that RAP experienced a 50 percent strength gain over 8-weeks while the SSG results indicated that the strength gain was 15 percent. The Clegg, FWD and SSG testing also indicated that RAP stiffness was similar to Limerock.

RAP-Soil mixes were evaluated by adding varying percentages of a poorly graded sand with clay, an A-2-6 (SM-SP) soil dredged from the Turkey Creek area in Palm Bay Florida. The 80 percent RAP- 20 percent soil mix produced the most desirable engineering behavior. Preliminary creep testing indicated that both the 100 percent RAP and the 80/20 Rap-Soil mix may pose long term deformation concerns.

The environmental evaluation indicated that RAP poses no environmental concerns when used as a highway material. The concentrations of heavy metals were well below the EPA standards. Samples were taken over a 12-month period and subjected to four different environmental testing procedures. All four yielded the same conclusions, indicating that the testing program was valid.

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Executive Summary

Developing Specifications for Using Recycled Asphalt Pavement as Base, Subbase, or General Fill Materials, Phase II

by

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Reclaimed Asphalt Pavement (RAP) stockpiles in Florida have grown because more stringent asphalt pavement SUPERPAVE specifications prevent re-using RAP as aggregate in Hot Mix Asphalt (HMA) production. The application of RAP as a Florida Department of Transportation (FDOT) approved base course, sub-base, and subgrade has been hindered due to low reported laboratory LBR tests.

During a Phase I study, a thorough laboratory and field investigation was conducted. The lab studies focused on evaluating the Limerock Bearing Ratio (LBR) performance of RAP and developing a database of the elementary geotechnical strength parameters such as friction, cohesion and elastic modulus.

The field study involved evaluating the strength gains of RAP over 12-months, through a variety of tests.

RAP was classified as a well-graded sand or gravel, with a top size of 1.5 inches. Measured asphalt content, specific gravity and absorption values were 6.73, 2.27 and 2.57 %. The moisture-density behavior did not follow traditional Proctor behavior. The resulting curves did not display a well-defined peak.

The basic geotechnical properties of friction, cohesion and elastic modulus were evaluated for RAP. The engineering properties of RAP proved to be desirable. They provide a sound basis to establish RAP as an accepted structural fill, or as a base or sub-base course in roadway construction.

The field site was constructed of RAP and a control section of cemented coquina. As was shown in the laboratory studies, the field strength of RAP was highly dependent on temperature. It increased and decreased during the cooler spring and warmer summer testing cycles respectively.

Initial LBR values for RAP averaged 16 and increased to 40 within two months. RAP LBR values exceeding 100 were recorded during the cooler months but could not be sustained during the warmer months.

A linear correlation was developed between the Impulse Stiffness Modulus (ISM) determined from the Falling Weight Deflectometer (FWD) and LBR values. FWD testing proved to be very reliable, quick, and accurate.

Based on the results of Phase I, it was concluded that RAP has potential to be used as a sub-base or subgrade, but did not display evidence that it could be used as an FDOT-approved base course.

The Phase II work focused on 1) validating the Phase I developmental specifications for using RAP as a base, sub-base or general fill, 2) evaluating the strength gain of RAP with in the first two months after construction, 3) evaluating RAP-Soil mixes in the laboratory and 4) evaluating the environmental performance of RAP in the field.

The Phase I Specifications were updated to allow RAP as a sub-base below rigid pavements. A second field site was constructed with RAP and a Limerock control section plus surface water and leachate water collection systems in both the RAP and Limerock. The initial strength gains were evaluated over an 8-week period and the environmental performance was analyzed over 12-months. Construction with RAP was equivalent or better to the construction with Limerock.

The strength-deformation behavior of RAP increased throughout the 8-week study period based on Field CBR data converted to LBR, ISM values from the FWD, and stiffness values from both the Clegg Impact Hammer and the Soil Stiffness Gage (SSG). LBR, Clegg and ISM data indicated that RAP experienced a 50 percent strength gain over 8-weeks while the SSG results indicated that the strength gain was 15 percent. The Clegg, FWD and SSG testing also indicated that RAP had stiffness similar to Limerock.

RAP-Soil mixes were evaluated by adding varying percentages of poorly graded sand with clay classified as an A-2-6 (SM-SP) soil. This soil was processed from dredged from the Turkey Creek area in Palm Bay Florida. The 80 percent RAP- 20 percent soil mix produced the most desirable engineering behavior. Preliminary creep testing indicated that both the 100 percent RAP and the 80/20 Rap-Soil mix may pose long term deformation concerns.

The environmental evaluation indicated that RAP poses no environmental concerns when used as a highway material. All concentrations reported of the heavy metals were well below the EPA standards. Samples were taken over a 12-month period and subjected to four different environmental testing procedures. All four yielded the same conclusions, indicating that the testing program was valid.

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1. Introduction

This report summarizes the findings of a second phase research project conducted for the Florida Department of Transportation. The first phase report entitled “Developing Specifications for Using Recycled Asphalt Pavement as Base Sub-base or General Fill Materials” was completed in March 2001 under Contract Number BB-892 (Cosentino and Kalajian, 2001).

1.1 Definition and Availability

Reclaimed asphalt pavement (RAP) is defined as pavement materials, containing asphalt and aggregates, which have been removed and/or reprocessed. In the United States asphalt pavement is the material that is most often recycled (Davis, 2000). There are an estimated 90 million tons of RAP milled yearly with 80% to 90% being reused in roadway repaving, translating into 18 million tons of RAP being available for other uses (Cosentino and Kalajian, 2001). With this volume available, there has been growing interest in using RAP for roadway construction and other fill applications.

1.2 RAP Usage in Florida

Florida, once led the nation in volume of recycled mix used in hot mix asphalt (HMA) production. There has been a steady decline in the amount of RAP being included in the HMA mixes. This decline can be attributed to the implementation of the SUPERPAVE (Superior Performing Asphalt Pavement) design mix adopted by Florida in 1998. In 1999, approximately 587 Mg (647,000 tons) of RAP were used in the production of approximately 2348 Mg (2,589,000 tons) of recycled mix, resulting in a 25% inclusion rate. This is a 2% decrease from the 27% inclusion rate of 1998. The use of RAP saved the state of Florida $13 million in materials costs in 1999 (FDOT, Asphalt Pavement Recycling Summary, 1994).

1.3 Engineering Characteristics

Previous research has shown that RAP has potential highway material uses. Doig (2000) reported RAPs' angle of internal friction (ϕ) ranged from 37 to 40 degrees, slightly less than the ϕ-values for limerock and cemented coquina of 44 and 41 degrees reported by Bosso (1995). Rodriquez (2001) reported that RAP was installed on high moisture content subsurface soils without construction difficulties or need for dewatering. Equipment operators likened installing RAP under these high moisture conditions to constructing with cemented coquina under favorable conditions (Rodriquez, 2001).

The main drawback preventing the use of RAP as a base course, has been the relatively low Limerock Bearing Ratio (LBR) values reported from laboratory testing (Rodriquez, 2001). Highway materials are typically categorized using stiffness and/or strength criteria. LBR-values are considered to be strength parameters, however, stiffness values obtained from falling weight deflectometer (FWD) tests indicate that RAP may be as stiff as cemented coquina (Rodriquez, 2001). This initial study showed that RAP gained stiffness throughout a 24-month period, with a significant gain in the first two months. Rodriquez (2001) also showed a possible linear relationship between the stiffness parameter obtained from FWD testing and the LBR-values determined from field CBR tests.

1.4 Environmental Characteristics

Townsend and Brantley (1998) investigated the leaching characteristics of RAP in a thorough laboratory investigation. The results lead to the conclusion that RAP poses minimal risk to groundwater as a result of pollutant leaching under normal land disposal or beneficial reuse. The pollutants investigated were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and selected heavy metals (Ba, Ca, Cr, Cu, Pb, Ni, and Zn).

To further validate RAP from environmental standpoint, field testing should be conducted.

1.5 Existing Specifications

The specifications that currently govern the selection and use of fill material used in Florida roadway construction were developed for use with conventional aggregates such as limerock, sand-clay, shell and rock material. These materials have to meet the specifications outlined in sections 911, 912, 913, and 913A respectively of the *Florida Department of Transportation Standard Specifications for Road and Bridge Construction, (2000).* The specifications include requirements for liquid and plastic limits, gradation and size, and Limerock Bearing Ratio.

Recycled RAP returned to the roadway can typically be incorporated into asphalt paving by means of hot or cold recycling, but it can also be used as an aggregate in base or subbase construction. According to the latest FDOT Road and

Bridge Specification in Section 283, RAP can be used as a base course only on paved shoulders, bike paths and other non-traffic applications (FDOT, 2000). An FDOT memorandum dated November 13, 2000 states that RAP is not permitted below the high water table elevation, in the top 6-inches of slopes and shoulders that will have grass or other type of vegetative establishment and as MSE backfill (Malerk and Xanders, 2000). Base course materials used in Florida are typically required to achieve a minimum LBR of 100, and subbase materials must have an LBR of at least 40 (Florida Department of Transportation, 2000).

1.6 Objective

The study objectives were to; 1) validate the Phase I Developmental Specifications for using RAP material as a base, sub-base or general fill, 2) evaluate the strength-deformation characteristics of RAP-Soil mixes and to 3) evaluate its environmental performance.

1.7 Approach

To meet these objectives both laboratory and field-testing programs were developed and completed over a 24-month period. The lab testing focused on determining the engineering properties of RAP-Soil mixes and the field testing focused on evaluating three items; the strength gains of RAP during the first 8-weeks after placement, the relationship between stiffness and strength of RAP and the environmental impacts of RAP.

To conduct the field-testing an outdoor test site composed of RAP and limerock was constructed and monitored at the APAC-Florida, Central Florida

Division – Melbourne Branch asphalt plant in Melbourne, Florida. Strength-deformation characteristics were measured during the eight weeks immediately following construction through the use of the following field tests: Field California Bearing Ratio (CBR), Falling Weight Deflectometer (FWD), Clegg Impact (CIT), and Soil Stiffness Gauge (SSG). Limerock was chosen as a control material, because along with cemented coquina, it is one of the most commonly used materials used in Florida roadway construction. Field CBR, FWD, CIT, and SSG tests were performed the first, second, fourth, sixth, and eighth week following construction. For each test, the results for RAP were compared to the results of the limerock. The effects of humidity, air, and ground temperature on the initial strength gains were also studied.

Environmental analysis samples were obtained from the surface water and leachate water collection systems, constructed in both the RAP and Limerock at the field site. Sampling was performed after significant rainfall events over a 12-month period. Laboratory studies, including Toxicity Characteristics Leaching Procedure (TCLP) tests (US EPA, 1992), Synthetic Precipitation Leaching Procedure (SPLP) tests (US EPA, 1994) and column leaching tests were conducted to produce a comparison between the surface water and leachate of the RAP and Limerock that would verify RAP's acceptance from an environmental standpoint.

2. Background & Theory

A complete literature review was conducted during phase I of this work. It included a summary table that indicated that RAP had compacted densities ranging from 109 to 130 pcf (17.1 to 20.4 kN/m^3), at moisture contents ranging from 4 to 7 percent. Rap classifies as a coarse grained material with a Unified Soils Classification System (USCS) symbol of GW or American Association of State Highway and Transportation Officials (AASHTO) symbol of A-1-a. The LBR values ranged from 11 to 239, however, the majority of values were less than 50 (Cosentino and Kalajian, 2001). RAP also displayed significant strength gains over the 12-month study. Depending upon the test method used, strength gains from 80 to 550 percent were determined. A large portion of these gains might have occurred during the 8-weeks immediately after construction. However, there was no testing during this time frame since the initial testing program called for testing at 2-month intervals for 12-months after construction.

Rap was also classified according to the process used after milling was completed. Two "post-milling-processes" were described, the hammermill and tubgrinder processes. The hammermill impact crusher is a type of horizontal impact crusher that is composed of a solid rotor and solid breaking bars. The RAP initially undergoes a high speed impact causing particles to rebound between the chamber and with other particles. The RAP is subjected to a second impact as the solid breaking bars and the striker plate collide. This second impact effectively crushes the RAP. When the impact speed is increased and/or when the distance between the striker plate and solid breaking bars is decreased, the hammermill process produces smaller particles. The hammermill crusher has a pivoting breaking bar on a rotor that produces a swinging-hammer type movement (Cosentino and Kalajian, 2001). In the tubgrinder process, a wall pushes the RAP towards a rotating drum containing milling spokes. This process compresses the RAP between two solid plates. The tubgrinder produces mostly coarse sand size material when grinding aggregate material. Upon completion of this study it was concluded that the post-milling processes evaluated had little effect on the engineering behavior of RAP. However, the post-milling portion of this study was not comprehensive since for example, the grinder settings were not varied from sample to sample to evaluate the effects on the grain size of the RAP.

2.1 Previous Lab Testing

Figure 2.1 depicts three typical Modified Proctor moisture-density curves for RAP obtained from various stockpiles at the APAC Florida Macasphalt plant located in Melbourne Florida. The results did not exhibit a classical moisture-density peak; rather the curves remained relatively flat indicating that RAP is insensitive to moisture content. Several other compaction techniques were evaluated including vibratory, a Modified Marshall compaction and Static compaction. Neither the Modified Marshall nor Static compaction techniques resulted in a more pronounced peak in the moisture-density curves. Figure 2.2 depicts the results from the vibratory compaction using relative density equipment. As is the case with sandy soils, RAP exhibited its highest densities at moisture contents near zero and at the largest moisture values. It was concluded that vibratory compaction at high moisture contents would result in the highest densities (Cosentino and Kalajian, 2001).

RAP compaction in the field site, constructed during Phase I, was accomplished using vibratory equipment after the site was thoroughly wetted with a water truck. The maximum dry density was achieved with this approach.

Vibratory compaction was also attempted at moisture contents near 5%, the optimum from Figure 2.1, and the results showed that the required density could not be achieved. This further substantiated the lab-testing conclusion (Cosentino and Kalajian, 2001).

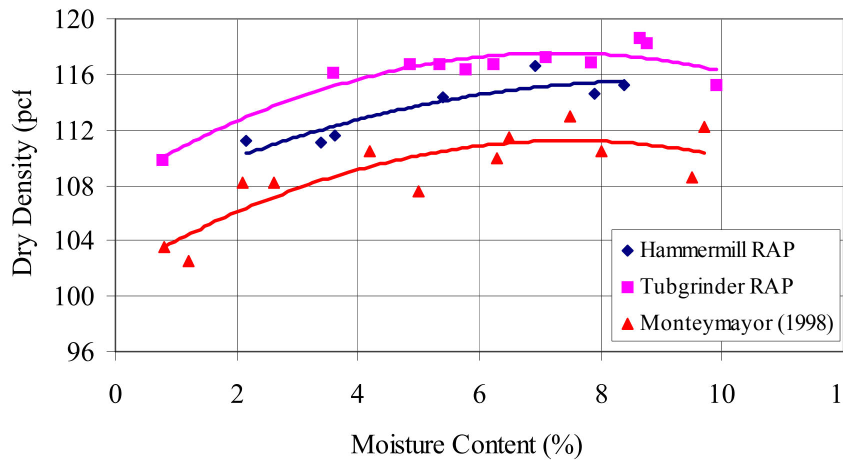

Figure 2.1 Typical Modified Proctor Moisture Density Relationships for Post Milled Process RAP (Cosentino and Kalajian, 2001)

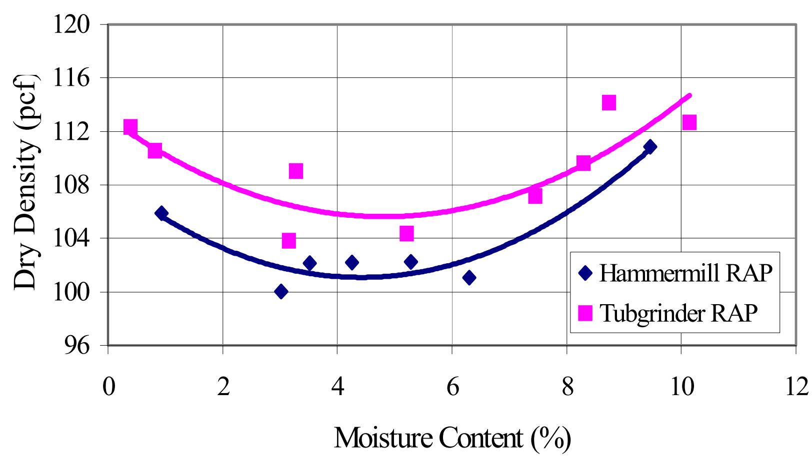

Figure 2.2 Dry density versus moisture content for RAP subjected to vibratory compaction (Cosentino and Kalajian, 2001)

The methods used to compact the RAP samples yielded a range of compacted dry densities between 100 and 125 pcf. As the dry density increases an increase in the bearing strength occurs, shown in Figure 2.3. To yield the required LBR strength of 100 for base courses, a density greater than 118 pcf had to be reached. These densities were only reached using the static method with a compaction pressure of 1000 psi.

Three distinct zones are shown in Figure 2.3. RAP samples with a compacted dry density below 109 pcf had LBR values below 30. RAP compacted to a dry density between 109 and 118 pcf had an LBR's from 10 to 75. The samples compacted statically typically had the larger LBR values. All samples with compacted dry density above 118 pcf had LBR values greater than 40, and as high as 149. Again, the higher LBR values occurred due to static compaction rather than the dynamic, vibratory or Proctor compaction methods. This trend seemed to indicate that a change in structure or binding with asphalt, increasing the bearing strength of the RAP.

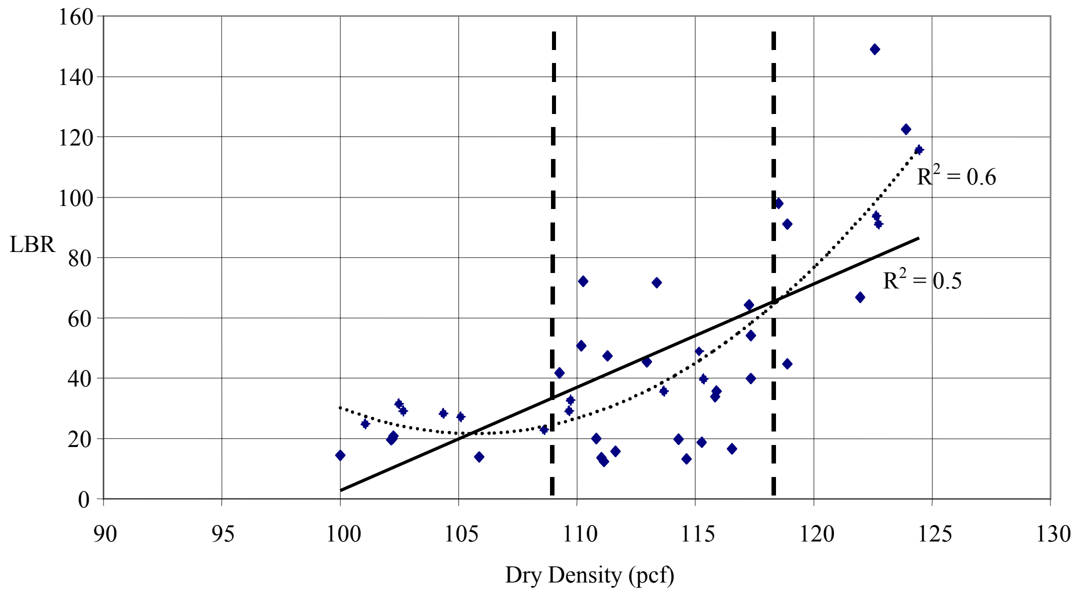

Figure 2.3 LBR versus dry density for RAP showing two possible regression lines through data (1 pcf=0.157 kN/m^3) (Cosentino and Kalajian, 2001)

The effects of compaction method were compared to the bearing strength as measured by the LBR test for the RAP. Figure 2.4 displays the range of bearing strengths, as measured by the LBR value.

The bearing strength of RAP, compacted using Proctor, vibratory, modified Marshall and 212 psi static was less than 45. The modified Marshall compaction method yielded the highest LBR values for a dynamic compaction method. This is attributed to the confinement provided by the plate during compaction. RAP samples displayed an increase in strength, as measured by the LBR value, when compacted statically. The minimum LBR value for soil used as a base in the state of Florida is 100. This was only reached by compacting RAP statically at an applied pressure of 1000 psi. An apparent change in the structure of the RAP occurred as the samples were statically compacted at greater pressures.

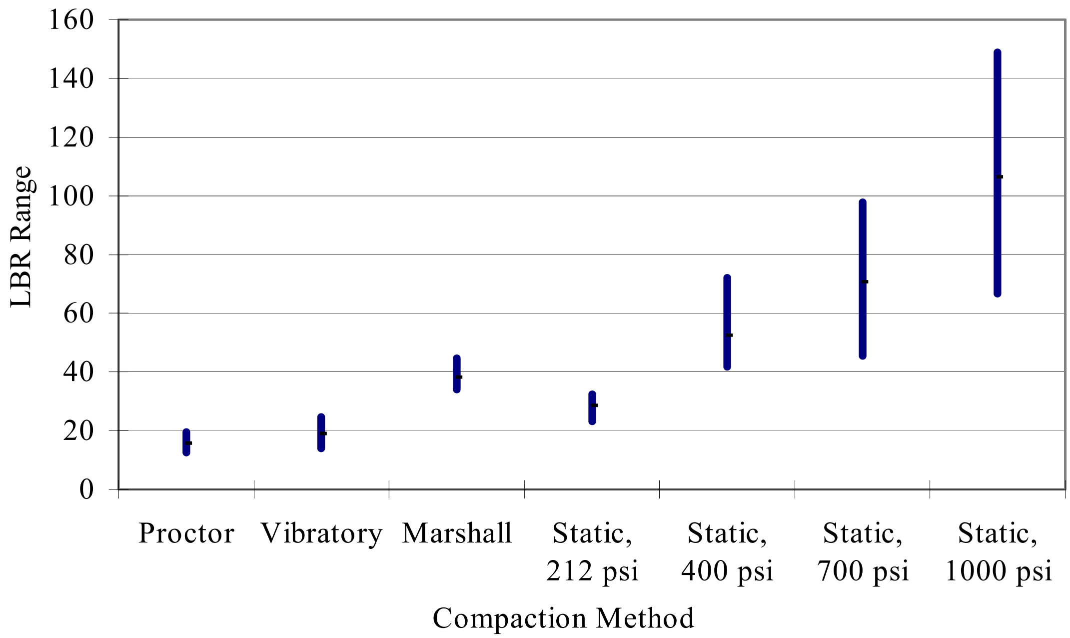

Figure 2.4 LBR versus compaction method for RAP (Cosentino and Kalajian, 2001)

2.2 Previous In-Situ Tests

In-situ tests on highways can be classified as destructive or non-destructive. Destructive tests can be defined as any test that alters the engineering characteristics of the material after it has been tested, therefore affecting ensuing tests. Non-destructive tests do not alter the engineering characteristics of the material (Rodriquez, 2001).

Rodriguez (2001) showed correlations from the results of dynamic testing with the Falling Weight Deflectometer (FWD) and the Automated Dynamic Cone Penetrometer (ADCPT) and LBR values determined from field CBR tests. Figure 2.5 shows the relationships developed from the ADCPT and LBR values. Webster et al (1992) developed a formula to predict bearing values based on the dynamic cone penetrometer index (DCPI) in blows/mm and it was included in this plot. Based on the DCPI values in the top 6-inches and Webster formula which is

$$LBR=365/(DCPI)^{1.12} \qquad (2.1)$$

it was concluded that the DCPI is related to the LBR.

Figure 2.6 shows the relationship between the Impulse Stiffness Modulus (ISM) determined from the FWD load-deflection data and the LBR. ISM values are determined by dividing the peak impulse force (kips) by the deflection of the first geophone (mils). Although the regression coefficient is somewhat low, the data still shows an increasing linear relationship between ISM and LBR.

The destructive tests performed during this investigation include the Limerock Bearing Ratio and the Nuclear Density Gauge. Non-destructive tests include the Falling Weight Deflectometer, Clegg Impact Hammer, and Soil Stiffness Gauge. The Clegg Impact Hammer and Soil Stiffness Gauge tests are relatively new. They are currently being evaluated by FDOT for uses in measuring in place soil stiffness and as a possible replacement of in-situ density testing. A brief description of each test is given in subsequent sections.

2.2.1 Stiffness and Strength

Strength and stiffness are two terms that are often used interchangeably, however, they are two separate concepts. Strength is defined as a measure of the maximum load per unit area, and can be in relation to tension, compression, shear, flexure, torsion, or impact. Stiffness is a relative measure of the deformability of a material under load (Somayaji, 2001). The field tests conducted during this investigation were classified as either strength or stiffness tests. The FWD, CIT, and SSG measure the stiffness of the material, whereas, the Limerock Bearing Ratio is a measure of shear strength (Head, 1981). Although the LBR is considered a strength parameter, it can also be considered as a stiffness parameter. It measures the load of a desired material, in pounds per inch, as compared to the load of an acceptable limerock at a deflection of 0.1 inch; therefore, it is a measure of relative stiffness. In other words material A with an LBR of 60 is not as stiff as a material B with an LBR of 100 since it takes more force to cause material B to deflect 0.1 inches than it does to deflect material A that same distance.

2.2.2 Falling Weight Deflectometer

The Falling Weight Deflectometer is one of the most common types of non-destructive testing equipment used for pavement evaluation and management. Use of the FWD has grown rapidly because of its ability to simulate traffic loading. The FWD produces a dynamic impulse load that simulates a moving wheel load, rather than a static, semi-static or vibratory load (Dynatest, 2000).

The loading range can be varied between 1,500 and 27,000 lbf (7 and 120 kN). A mass is dropped from a known height producing a dynamic load and a deflection basin. The loads, measured using a load cell, are transferred to the roadway through an 11.8-inch (30 centimeter) diameter rubber plate. The

deflection (D_o) was used to compare the CA-6 and RAP bases. Among the conclusions drawn by Garg and Thompson (1996) were that FWD results indicate that RAP can be successfully used as a conventional flexible pavement base material based on the FWD deflection data. Center plate deflections for RAP and CA-6 ranged from 14 to 20 and 13 to 18, respectively. FWD data indicates that the RAP base provided adequate structural support and subgrade protection. The authors also noted that the performance of RAP base pavement is comparable to that of the crushed base stone (Garg and Thompson, 1996).

Sayed et al. (1996) performed a study to assess the applicability of UNtreated Recycled Asphalt Pavement (UNRAP) as a base for pavement sections. Limerock was used for a control material in this study. FWD tests were conducted immediately after construction and four months later. UNRAP produced lower deflections during both testing cycles. This suggests the limerock base is less stiff compared to the UNRAP base. Sayed et al. (1993) concluded that the Falling Weight Deflectometer tests suggest that "UNRAP is at least equivalent to limerock".

2.2.3 Clegg Impact Test

During the 1970s Dr.Baden Clegg developed the Clegg Impact Soil Tester, commonly known as the Clegg Hammer. Although not commonly used in the United States, it is routinely used in other countries for quality control of density and strength requirements of base, subbase, and subgrade layers (Janoo, 1998). The basic principle of this test is that the peak deceleration of a compaction hammer when it is brought to rest is directly related to the resistance offered at contact resulting from the stiffness and shearing resistance of the material (Clegg, 1980). A schematic of the Clegg Hammer is shown in Figure 2.9. It consists of a hammer to which a piezoelectric accelerometer is attached, a guide tube and an electronic display. The hammer is a Modified Proctor compaction hammer

2.2.4 Soil Stiffness Gauge

The SSG was developed as part of a joint investigation sponsored by the Federal Highway Administration (FHWA) and the United States Department of Defense. Currently the SSG is the subject of a twenty-two state pool funded investigation. The SSG is being considered as an alternative to the nuclear density gauge in controlling the compaction of soils during roadway construction (TR News, 2001). The SSG measures the in-place stiffness of compacted soil at a rate of about one test per minute (Fielder et al, 1998). A schematic of the SSG is shown in Figure 2.10.

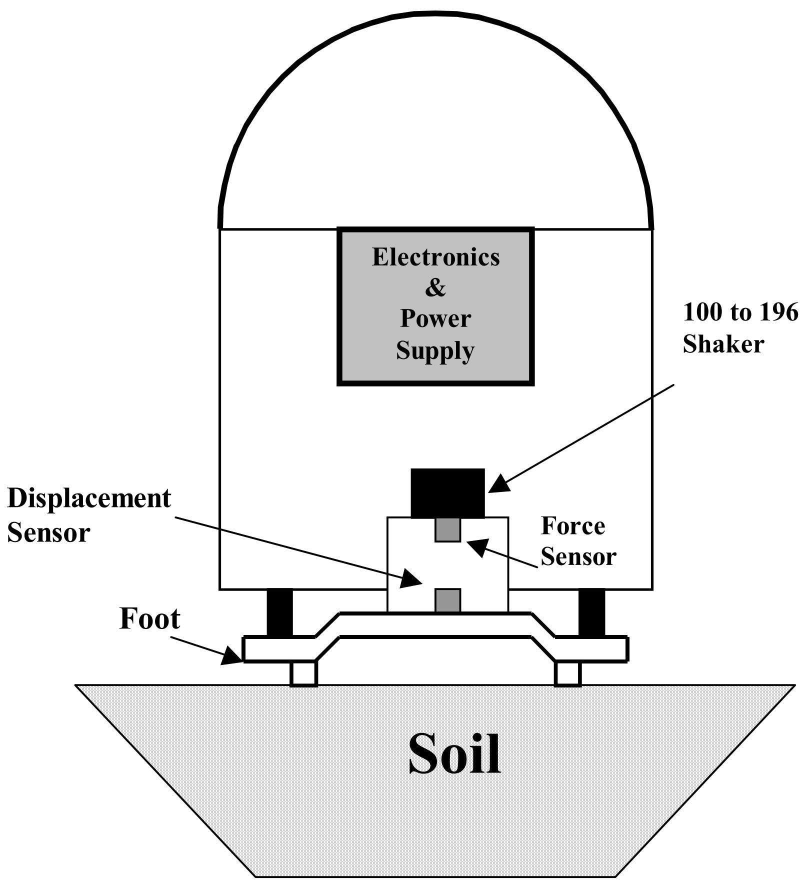

Figure 2.10 Schematic of the Soil Stiffness Gauge (Model H-4140)

The SSG test is performed by seating the device on the soil and gently rotating it back and forth to obtain the 60% required minimum contact area between the SSG foot and the soil. Once this is completed, the measure key (denoted as “Meas”) is depressed and the SSG measures site noise and stiffness as a function of frequency. The gauge will display average stiffness, lb/in (Mn/m) or modulus, psi (MPa). The SSG can store 500 measurements while working in operational mode. It has a stiffness measurement range from 17,000 lb/in to 126,000 lb/in (3 to 22.1 MN/m) and a Young’s Modulus measurement range of 3,800 to 28,000 psi (26.2 to 193 MPa). The depth of influence is between four and six inches from the surface (Fielder et al, 1998). The SSG simulates soil stress levels (4 psi or 28 kPa) common for pavement, bedding, and foundation applications (Fielder et al, 1998).

2.2.5 Limerock Bearing Ratio

Limerock Bearing Ratio tests have long been used for flexible pavement design in Florida. The LBR test is a modified CBR test, which has become one of the most widely, used and recognized soil strength parameters. The LBR test as used in flexible pavement design in Florida is a measure of the bearing capacity of a soil. The test consists of plunging a 3 in^2 circular piston at a specified rate and measuring the load required to force the piston into a soil specimen 0.1 inch, divided by the load in psi required to force the same piston 0.1inch into a crushed limerock sample. The standard penetration load for crushed limerock in Florida is 800 psi. This ratio is multiplied by 100 and the percent sign is omitted thus given the LBR value (Ping and Yu, 1994). Field LBR testing was performed according to ASTM D 4429-93 (*Standard Test Method for CBR (California Bearing Ratio) of Soils in Place)*. The CBR values were converted to LBR values by multiplying them by 1.25. The 1.25-multiplier results when the standard CBR load at 1000 psi is divided by the standard LBR load at 800 psi for the Florida Department of Transportation test method (Florida Method of Test for Limerock Bearing Ratio FM-5-515).

Rodriquez (2001) conducted a field study to analyze the construction and performance of RAP in the field. RAP used in the study classified as a well-graded sand (SW) according to the Unified Soil Classification System (USCS). Among the conclusions Rodriquez (2001) formulated was that, according to field LBR theory RAP is not a feasible material for use as a base because it does not sustain the FDOT minimum requirements for base material (LBR = 100). However, RAP did sustain a minimum LBR of 40 for approximately 80% of the tests and therefore has potential to be utilized as a subbase and/or subgrade.

The Florida Department of Transportation conducted a study to evaluate the use of UNRAP (untreated RAP) as a base course material in the construction of road shoulders. Limerock was used as a control material. The UNRAP classified as a GW (well-graded gravel) based on the USCS. Laboratory LBR's were conducted on both soaked and unsoaked samples. The LBR values ranged from 25 to 30 for the soaked and 29 to 38 for the unsoaked (Sayed, et al., 1993). Field LBR's were also conducted during the study. The average field LBR attained for the UNRAP was 29, with values ranging from 15 to 54. The average field LBR on the limerock was 77 (Sayed, et al., 1993).

2.3 Relative Humidity

Relative humidity is the most common way of describing atmospheric moisture. The relative humidity (RH) is an indicator of how close the air is to being saturated. RH is the ratio of the amount of water vapor actually in the air to the maximum amount of water vapor required for saturation at that particular temperature (Ahrens, 2001). This relationship is shown below in equation format.

$$RH = \frac{water\ vapor\ content}{water\ vapor\ capacity} \times 100 \qquad (2.6)$$

Relative humidity is usually expressed as a percent. For example air with a 50% RH contains one-half the amount required for saturation. Air with 100% RH is said to be saturated, and air with relative humidity greater than 100% is said to be supersaturated. Relative humidity can be changed by changing the air's water vapor content or by changing the air temperature (Ahrens, 2001). RH is inversely related to air temperature. With constant water vapor content, increasing air temperature lowers the relative humidity, while decreasing air temperature will increase the relative humidity. Therefore relative humidity will be the highest during the morning hours and decrease as the air temperature warms up during the day (Ahrens, 2001).

2.4 Previous Environmental Lab Testing

Townsend and Brantley (1998) investigated the leaching characteristics of RAP by conducting both batch-scale and leaching columns tests. The primary leachable pollutants investigated were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and selected heavy metals (Ba, Ca, Cr, Cu, Pb, Ni, and Zn).

The batch-scale tests were EPA TCLP and SPLP that were performed to determine if the RAP tested was a hazardous waste. Both TCLP and SPLP results

3. Methodology

3.1 Material Sampling for Field Site Construction

RAP samples were obtained from the hammermill post-milling processed stockpile at the APAC-Florida, Inc. asphalt plant located in Melbourne, Florida. Several hundred pounds of this material were taken, in accordance with ASTM D75 "Standard Practice for Sampling Aggregates", to insure that a thorough laboratory-testing program could be completed to aid in the construction of the field site. The hammermill grinder separates the larger RAP material with a screen before it is fed into a swing-hammer impact crusher. The swing-hammer impact crusher reduces material to sizes of ½ an inch or smaller. The processing of RAP is most commonly performed throughout the United States with the hammermill grinder. Limerock from the Mazak Mine (FDOT mine# 18-522) located in Webster, Florida was also sampled following ASTM D75 standards.

3.1.1 Grain Size Distribution

Sieve analyses were performed following ASTM C136-93, *Standard Test Method for Sieve Analysis of Fine and Course Aggregates*. RAP and limerock samples were dried at room temperature before performing the sieve analyses. The sieve sizes used during the sieve analysis were 1.5 inch, 0.75 inch, 0.375 inch, #4, #8, #16, #30, #60, #100, and #200.

Three samples of approximately 1500 grams each were tested to produce an average gradation curve for each material. From the gradation curves the D_{10}, D_{30}, and D_{60}, gradation parameters were determined. These parameters represent the grain diameter (in millimeters) at 10, 30, and 60 percent passing by weight (Holtz and Kovacs, 1981). The coefficient of curvature (C_c) and uniformity (C_u) were also calculated. Classification of the materials was made using the United Soil Classification System (USCS) and the American Association for State Highway Transportation Officials (AASHTO).

3.1.2 Asphalt Content

Asphalt content tests were performed on RAP samples using test method FM 5-563 (*Quantitative Determination of Asphalt Content from Asphalt paving Mixtures by the Ignition Method*) of the 2000 Florida Sampling and Testing Methods Manual. Four samples of approximately 1550 grams were tested, to determine an average asphalt content value. The FDOT, District 5 Materials and Research Division, located in Deland, Florida conducted the tests.

3.2 Field Site Development and Layout

A field site has been chosen for construction at the APAC-Florida, Central Florida Division – Melbourne Branch asphalt plant. The site was approximately 60 feet by 120 feet. It was divided into two major sections, one was constructed of RAP and the other was constructed from limerock. Each section included a 5 foot by 5 foot collection system for the collection of the runoff and leachate to be studied as part of FDOT research contract "*Developing Specifications for Using*

3.3 Field Site Construction

Construction of the field test site began on Monday, April 16, 2001 and required approximately six days to complete. No rain occurred during construction and temperatures averaged 78^{o}F. The material used at the Phase I field site of this project was removed to a depth of 12-inches below the surface. The materials removed consisted of RAP and cemented coquina. They were remixed with a tiller and compacted with ten passes from a smooth drum vibratory roller, to form a subgrade for the new site. Figure 3.2 shows the mixing of the materials to create the uniform subgrade.

Figure 3.2 Mixing of RAP and Cemented Coquina from Phase I to form uniform subgrade for Phase II

Figure 3.4 Completed Highway Materials Test Field Site

3.4 Testing Cycles

Table 3.1 shows the type of tests and the number of tests per cycle that were conducted at the field site. The tests were performed during the first, second, fourth, sixth, and eighth week following construction. The testing program started on April 25, 2001 and concluded on June 14, 2001.

3.5 Testing Procedures

3.5.1 Falling Weight Deflectometer

No specifications were found for conducting the FWD test. Twenty-five tests were performed per test cycle, twenty-one on RAP and four on limerock. Each test took approximately two minutes to complete. For each test location three load levels were targeted, 6000, 9000, and 12000 lbf. Deflections from seven geophones spaced at 0, 8, 12, 18, 24, 36, and 60 inches from the load plate were recorded. Temperature data was also recorded. All data was obtained in both hardcopy and 3.5-inch floppy disk format.

3.5.2 Clegg Impact Test

Tests were performed according to ASTM D 5874 (*Determination of the Impact Value (IV) of a Soil*). Thirty-three tests were performed per testing cycle, twenty-four on the RAP and nine on the limerock. Similarly to the FWD, the Clegg test took about one minute to complete. At each test location three Clegg tests were performed, the tests were centered around the location of the Nuclear Densometer tests. The Clegg hammer was dropped four times on the same location, with the highest value of the four used for data analysis (Clegg, 1980).

3.5.3 Soil Stiffness Gauge

Standard specifications governing how to perform this test have not yet been developed since this device is relatively new. Thirty-three tests were performed per testing cycle, twenty-four on the RAP and nine on the limerock. At each test location three SSG tests were performed, the tests were centered around the location of the Nuclear Densometer tests. Each test was completed in about two minutes. The average of all three tests were taken to establish a stiffness value for each location.

3.5.4 Limerock Bearing Ratio

LBR values were calculated by performing field CBR tests according to ASTM D 4429-93 (*Standard Test Method for CBR (California Bearing Ratio) of Soils in Place)*. Eleven tests were performed per testing cycle, eight on the RAP and three on the limerock. Field CBR tests required approximately 25 minutes to complete. At each test location one field CBR was performed, the tests were averaged to generate one field CBR value for RAP and one field CBR value for limerock per testing cycle. These values were then converted to field LBR values using the following equation (Florida Method of Test for Limerock Bearing Ratio FM-5-515), as described in Section 2.2.5:

$$LBR = 1.25CBR \qquad (3.1)$$

3.5.5 Calcium Carbide Gas Pressure Moisture Tester

Calcium Carbide Gas Pressure Moisture tests were performed according to FM 5-507 (*Determination of Moisture Content by Means of a Calcium Carbide Gas Pressure Moisture Tester*) of the 1994 Florida Sampling and Testing Methods Manual. These tests were performed at the site by FDOT personnel to determine in-situ moisture contents.

Three tests were performed on each material per testing cycle. The tests were averaged to obtain a moisture content for each material. The average test time for Calcium Carbide Gas Pressure Moisture tests was about five minutes.

3.5.6 Nuclear Densometer

Wet Density testing was performed according to FM 1-T 238 (*Density of Soils and Bituminous Concrete Mixtures In Place By the Nuclear Method*) of the 1994 Florida Sampling and Testing Methods Manual. FDOT personnel performed the tests and each test required about two minutes to perform.

Eleven tests were performed per testing cycle, eight on the RAP and three on the limerock. At each test location two nuclear density tests were performed, one at six inches and one at twelve inches. The wet density for each location was recorded. Moisture contents taken from the Calcium Carbide Gas Pressure Moisture Tester were used to calculate dry densities. The nuclear densometer equipment records moisture contents for materials approved by the state, such as cemented coquina and limerock. RAP is not an approved material; therefore moisture contents were obtained using a Calcium Carbide Gas Pressure Moisture Tester. The tests were averaged giving an average dry density for RAP and one for limerock per testing cycle.

3.5.7 Temperature and Humidity Loggers

Data loggers were used to monitor air and ground temperature as well as humidity over the course of this investigation. Air temperature and humidity were monitored using HOBO® H8 Pro RH/Temperature Loggers. A photograph of the HOBO logger can be viewed in Figure 3.6.

Figure 3.6 HOBO® H8 Pro RH/Temperature Loggers

3.6 RAP-Soil Mixtures Methodology & Test Procedures

3.6.1 Introduction

RAP was mixed with a soil at various percentages by weight. The soil selected for mixing with RAP was a fine sand-trace of organics that was processed from muck obtained from a local dredging project and is referred to as fine sand for this investigation. Sieve analysis, Atterberg limits, specific gravity, asphalt content, and organic content tests were performed to characterize the RAP, fine sand, and RAP-soil mixtures. The engineering properties of the RAP and RAP-soil mixtures were evaluated by performing dry rodded unit weight, moisture-density, permeability, Limerock Bearing Ratio, static triaxial compression, and resilient modulus tests.

Dry rodded unit weight results were used to make initial decisions on the selection of RAP-soil mixtures to be used for further testing. Moisture-density curves were then developed to identify the optimum moisture contents and maximum dry unit weights of the selected mixtures. The remaining tests were conducted on RAP-soil mixtures compacted at their respective optimum moisture contents using modified Proctor compaction effort. Strength parameters of the mixtures were determined by the LBR, static triaxial compression, and resilient modulus tests. Drainage characteristics of the mixtures were evaluated through permeability tests.

3.6.2 Selection of RAP-Soil Mixtures

The RAP-soil mixtures used in this investigation were based on dry rodded unit weight tests performed on mixtures with varying RAP percentages. The results to be presented in Chapter 4, show a distinct peak dry rodded unit weight for a mixture containing 80% RAP. The dry rodded unit weight increased as the RAP percentage increased from 60 to 80, and then decreased as the RAP percentage increased from 80 to 100. Therefore, mixtures of RAP with a fine sand at the following proportions by weight were selected for further testing: 100% RAP, 80% RAP – 20% soil, and 60% RAP – 40% soil.

3.6.3 Material Sampling

RAP samples were collected from the top 12-inch lift of the field site (Section 3.2) following the FDOT *Manual of Florida Sampling and Testing Methods 1994*, procedure FM 1-T 002, "Sampling Coarse and Fine Aggregate." The RAP used in the construction of the field site was obtained from a stockpile of hammermill post-milling processed RAP at the APAC-Florida, Central Florida Division – Melbourne Branch asphalt plant.

The fine sand used for mixing with RAP was processed from muck obtained from a spoil storage/dewatering area located at the intersection of US1 and Conlan Blvd. in Melbourne, Florida. The material was dredged from the mouth of Turkey Creek by the Saint Johns River Water Management District and transported to the spoil area. The spoil area serves as a large settling pond to separate the sediments and water (BCI, 1996). After the solids settle to the bottom, the clear liquid is drained and the solids allowed to dry by evaporation. To improve the drying process, solids were removed from the bottom of the settling pond and spread on an open field around the spoil area, increasing the surface area and thus allowing for quicker evaporation to take place. Samples for this study were collected over a period of 12 months at different locations of the spread material. The choice of location for sampling depended on the visual characteristics of the soil. Typically the dryer material displayed a lighter color than wet material. Dry material was preferred for ease of handling and reduced drying time.

3.6.4 Sample Preparation

All the RAP used for testing was air dried at room temperature and modified in size according to procedures outlined in section 3.2 of FM 5-521 and FM 5-515. The RAP obtained from the field was air dried for 4 to 5 days on flat metal trays at room temperature (approximately 75^{o}F). RAP was air dried rather than oven dried to prevent changes in its behavior due to the presence of asphalt binder. The size modification follows the sample preparation procedure for the Modified Proctor Compaction and Limerock Bearing Ratio tests, and was maintained for the remaining tests to allow for a relatively constant grain size distribution throughout the testing program. Material passing the 2 inch sieve and retained on the ¾ inch sieve was weighed and replaced by an equal weight of material passing the ¾ inch sieve and retained on the # 4 sieve. Material retained on the 2 inch sieve was discarded. The modified RAP was reduced for laboratory mixing and testing by the quartering method outlined in FM 1-T 248, "Reducing Field Samples of Aggregate to Testing Size."

The material obtained from the spoil storage/dewatering area was oven-dried at 60^{o}C. Dry solid particles larger than 1 inch were reduced in size using a 10 pound hammer with an 18 inch drop height. The particles were further reduced

3.6.5.2.2 Moisture-Density

The relationship between dry density and moisture content of the RAP-soil mixtures was determined according to FM 5-521 (FM 1-T 180). Samples were compacted in 5 equal layers with 56 blows per layer using a 10 pound hammer and an 18 inch drop height, yielding a compactive effort of 56,000 ft-lb/ft^3. Compaction was done with a mechanical compaction machine manufactured by Ploog Engineering Company, Inc. Standard 6 inch diameter compaction molds with volumes of 0.075 ft^3 were used. Samples were prepared at moisture contents ranging from 3 to 11% and allowed to hydrate overnight prior to compaction.

3.6.5.2.3 Permeability

Permeability of the 100% RAP specimens was determined by constant and falling head tests according to FM 1-T 215 and FM 5-513 respectively. Samples were compacted in a standard 4 inch diameter compaction mold with a ¼ inch spacer disk. The spacer disk was used to provide the necessary spacing for the placement of the porous stone at the top of the specimen in the rigid wall permeameter. After compaction, the specimens were prepared in the rigid wall permeameter and left to permeate overnight with the constant head setup to ensure proper saturation prior to testing. Samples were tested first using the constant head setup and upon completion the same sample was tested using the falling head setup. Tap water was used as the permeant for testing.

The permeability of the 80 and 60% RAP samples were expected to be lower than 100% RAP and were determined using a flexible wall permeameter according to ASTM D 5084, Method C – Falling Head, rising tailwater elevation (ASTM, 2002). Samples were compacted in a 4 inch diameter mold (similar mold as for 100% RAP samples), weighed, and extruded with a hydraulic jack. The diameter and length were recorded prior to placement of the specimen in the permeability

3.6.5.2.5 Static Triaxial Compression

The elastic modulus, maximum stress at failure, and shear strength of the RAP and RAP-soil mixtures was determined by consolidated-drained (CD) triaxial compression tests. The sample preparation and testing procedures followed in conducting the triaxial tests were adopted from ASTM D 4767, "Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils" (ASTM, 2002) and the "Manual of Soil Laboratory Testing: Volume 3" by Head (1986). Samples were prepared at their respective optimum moisture contents and allowed to hydrate overnight prior to compaction. A 4 inch diameter, 8.375 inch high mold was used for compaction. The material was manually compacted in 6 equal layers with 38 blows per layer using a 10 pound hammer and an 18 inch drop height, yielding a compactive effort of 56,153 ft-lb/ft^3. The sample was weighed after compaction and then extruded with a hydraulic jack from the mold. The diameter and length were recorded prior to placement of the specimen in the triaxial cell. A porous stone and filter paper were placed on the base pedestal of the cell, after which eight ¾ inch wide filter paper strips were spaced radially on the circular filter paper placed on the porous stone. After placement of the sample, the filter paper strips were folded and attached vertically to the side of the specimen and folded on top. Another circular filter paper and porous stone was placed on top with a top cap. A latex membrane was placed around the sample and sealed with rubber O-rings. The chamber was filled with water and the drainage lines were left open to atmosphere. A triaxial sample is shown in Figure 3.9.

was measured with burettes open to atmosphere that were connected to the top and bottom drainage lines of the triaxial cell. The rate of loading during compression was estimated from consolidation results. A 60% RAP permeability sample was consolidated following procedures outlined by Head (1986). The maximum loading rate for samples with side drains was estimated to be 0.002 inch / minute. However, due to limitations of the loading machine, the slowest possible loading rate of 0.005 inch / minute was selected. Two samples were tested at effective consolidation pressures of 5 and 15 psi for each RAP and RAP-soil sample.

3.6.5.2.6 Resilient Modulus

Resilient modulus tests of the RAP and RAP-soil mixtures were conducted by FDOT personnel at the State Materials Office in Gainesville, Florida. The Long-Term Pavement Performance (LTPP) Protocol P46 test procedure for "Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils" as described by Alavi et al. (1997) was followed. The RAP obtained from the field was modified in size for testing by passing the entire sample through a jaw crusher set at a maximum opening of ¾ inch. The RAP and RAP-soil mixtures were prepared at their respective optimum moisture contents and allowed to hydrate overnight prior to compaction. The samples were compacted in 4 inch diameter, 8 inch high compaction molds using a mechanical compaction machine. Samples were compacted in 6 equal layers with 38 blows per layer using a 10 pound hammer and an 18 inch drop height, yielding a compactive effort of 58,785 ft-lb/ft^3. After compaction the samples were extruded from the mold and placed on the triaxial base pedestal. A porous stone was placed at the top and bottom of the sample with filter paper placed between the sample and porous stones. A top cap was positioned on the top of the specimen followed by the placement of a latex membrane around the sample. The membrane was sealed to the base pedestal and top cap with rubber O-rings. The RAP and RAP-soil mixtures were tested as base

3.7 Preliminary Creep Testing Methodology

3.7.1 Typical Creep Behavior of Soils

Creep, or slow shear movements, begins to occur when shear stresses in soils increase as a function of the total shear strength. Generally sandy and gravelly soils can sustain shear stresses very close to their shear strength for long periods without failing, and is one of the reasons that these soils are superior materials for many applications. Although RAP is classified as an A-1-a soil, indicating that it is typically a gravel/sand mixture, it is still necessary to determine whether creep is a concern due to the asphalt content that the RAP possesses.

Creep behavior of soils under a constant stress may vary depending upon the level of the stress being applied. Under relatively low shearing stresses, creep movements may be small and cease after some period of time. Under higher stresses, creep movements may continue indefinitely. In some soils, continued application of stress may result in acceleration of the creep rate followed by complete rupture.

These time-dependent responses of soils may take on a variety of forms depending on such factors as soil type, soil structure, stress history, drainage conditions, type of loading, and other factors. It is necessary to determine into what pattern of long-term creep behavior RAP falls.

3.7.2 Development of Creep Testing Methodology

Although many studies have been performed on cohesive soils to determine creep behavior, very few have been completed with the focus on non-cohesive soils. As a result, no procedural guidelines were found for the testing of creep in a granular material such as RAP. Consequently, a preliminary testing method was derived by FIT from the basic underlying concepts and procedures applied for creep testing in cohesive soils, as well as LBR testing that has been performed on RAP.

Three factors were measured to evaluate the creep characteristics of RAP; stress, deflection, and time. The testing was conducted by using a *Brainard-Kilman Terraload Consolidation Load Frame.* Three samples were prepared for separate testing in 6-inch diameter proctor molds according to ASTM-1557 Method D with a moisture content of 10%, which is slightly wet of optimum. The three materials tested were 100% RAP, a RAP-soil mixture of 80% RAP and 20% soil, as well as for A-3 soil, which was used as the control. The general setup of the testing apparatus can be seen in Figure 3.10.

By evaluating several Load Penetration Curves from previous LBR testing, an ultimate strength of RAP was determined. With an estimated 800psi as the 100% ultimate strength level, various percentages of this strength were chosen for the application loads. The sample was loaded with a 1.95-inch diameter ($3in^2$) piston, which is traditionally used for LBR testing. Loads were maintained for a minimum of 4000 minutes, provided that sample failure did not occur prior to this point. The samples were incrementally loaded with 33.5psi, 67psi, 134psi, and 268psi, which respectively correspond to 4.2%, 8.4%, 16.7% and 33.5% of the ultimate strength.

3.8 Environmental Testing Methodologies

3.8.1 Site Construction

The 5-foot by 5-foot runoff and leachate collection systems constructed as part of the field site were situated so as not to be disturbed by engineering evaluation on the site (See Figure 3.1). Perforated PVC piping (4-inch diameter) was included near the surface to collect surface waters and on the geomembrane to collect the leachate waters. The surface slopes, graded to approximately 2 %, were sufficient to cause water that contacted these areas to flow towards the collection system. The infiltrated water was prevented from passing through the RAP or limerock layer due to an impermeable 40-mil geomembrane that was placed beneath it. The perforated PVC pipes were wrapped in geotextile fabric designed to allow water to pass through but prevent clogging by the RAP or limerock particles. These pipes were sloped toward the outer edges of the collection system to 2-inch diameter pipes that were sloped towards the collection drums (See Figure 3.11). Two 55-gallon plastic drums were connected to the collection systems for both the surface runoff and leachate (See Figure 3.11). Following construction of the drainage system, both the RAP and Limerock sites were backfilled to final grade, by placing 8-inch loose lifts of material and compacting them with a vibratory compactor to 6-inch lifts. The density of the materials in these sections was not equivalent, because the compaction equipment (Figure 3.3) could not be used in these confined areas.

Figure 3.11 Photograph of Limerock Collection Systems prior to backfilling with Limerock

3.8.2 Environmental Field Monitoring

Figure 3.12 shows the completed RAP and Limerock collection systems. Depending on the rainfall events, environmental monitoring and sampling were performed monthly for the first three months and bi-monthly thereafter. Both surface runoff and leachate were collected for analysis of cadmium (Cd), chromium (Cr), lead (Pb), selenium (Se), and silver (Ag).

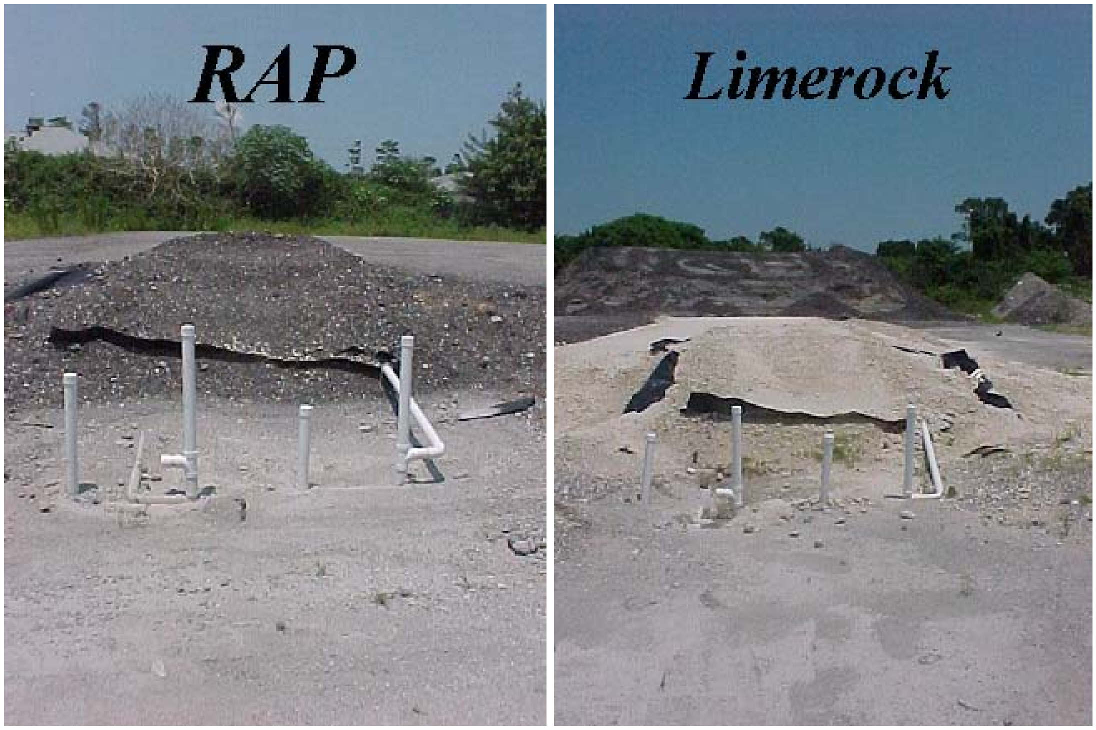

Figure 3.12 Completed RAP and Limerock Collection Systems

3.8.2.1 Sampling

Both surface and leachate water samples were collected from the RAP and limerock sites for chemical analysis. Samples were only collected when at least 2-inches of liquid had accumulated in the collection drums. Samples were collected immediately after a rainfall event and preserved immediately by acidifying to below pH 2 prior to exporting them back to the laboratory for analysis. Quantities of accumulated liquid samples in the collection drums were recorded to enable assessment of leaching characteristics of the RAP and the control limestone sites.

3.8.2.2 Chemical and Instrumental Analysis

A Perkin-Elmer Model 5100 Atomic Absorption Spectrophotometer (AAS) equipped with Zeeman background correction was used for leachate analysis. Analyses of trace metals were performed by using graphite furnace AAS. Different

3.8.3.3 Column Leaching Test

The column-leaching test was designed to determine the environmental impact of RAP being used as a subsurface highway material. Five columns were constructed to investigate leaching characteristics of RAP and limerock under controlled situations in laboratory.

The column-leaching test, modified from ASTM D2434-68 Standard Test Method for Permeability of Granular Soils (Constant Head) and ASTM D4874-95 Standard Test Method for Leaching Solid Material in a Column Apparatus, was conducted to investigate the leaching of RAP in controlled solution. The column was made of PVC, which had a diameter of 10.2 cm (4 in) and a height of 76.2 cm (30 in). The column was mounted on a platform and a screen and drainage tube was installed in the bottom of the column. Leachate from the column was collected over different time intervals. A schematic of the column is depicted in Figure 3.15. The rainfall simulation nozzle was installed on the top of the column, as shown in Figure 3.16, to simulate average rate of rainfall in the adjacent areas of the field site. The Standard Proctor Compaction technique (ASTM D-698) was used to compact the RAP and Limerock samples. Leaching column samples used in this study were compacted by using 2.5 kg (5.5 lb) PVC hammer and 12-inch (304.8 mm) drop that was the compaction technique according to the Standard Proctor compaction test (Das, 1989) modified for environmental concerns.

The construction of the column was carried out to simulate field conditions, including test material, thickness and compaction techniques. Leaching media for column tests were DDW and synthetic acid rain that was prepared according to the National Atmosphere Deposition Program (NADP) quality reference to simulate acid rain common to the Northeastern United States (U.S. EPA, 1990). Column leaching samples were collected for analysis of cadmium, chromium, lead, selenium, and silver. Analytical data generated in the laboratory study were correlated to the results of field study.

4. Presentation and Discussion of Results

4.1 Grain Size Distribution

The gradation curves for the RAP and limerock, using the average of three tests samples, are shown in Figure 4.1. RAP was classified as well-graded gravel (GW) and limerock classified as well graded sand (SW) using the Unified Soil Classification System (USCS). Based on the American Association for State Highway and Transportation Officials (AASHTO) standards, RAP was classified as an A-1-a and limerock classified as an A-1-b.

Table 4.1 shows a summary of the gradation parameters, D_{10}, D_{30}, and D_{60}. The coefficient of curvature (C_c) and coefficient of uniformity (C_u) are also presented in Table 4.1. The RAP being used compares well to the RAP used in the previous studies. The major difference is that the newest material was classified as gravel and the RAP samples from previous investigations were classified as both sand and gravel. The effective grain size (D_{10}) has an important influence on permeability (Holtz and Kovacs, 1981). It is proportional to permeability, meaning the larger the D_{10} the more permeable the material. RAP and limerock used in this investigation had effective grain sizes of 0.43 and 0.25 mm respectively. Based on its D_{10} –value, RAP would be expected to have better drainage characteristics than limerock.

4.2 Asphalt Content

The average asphalt content was 6.04 ± 0.01 percent for the RAP used in this investigation. Rodriquez (2001) and Montemayor (1998) reported asphalt contents of 6.73 and 5.67 percent respectively. The expected range for asphalt content is 4 to 8 percent by weight, for structural asphalt concrete mixtures used in Florida (Montemayor, 1998).

4.3 Falling Weight Deflectometer

Calculations done using MODULUS 5.1 indicated that very slight changes in layer thickness caused large changes in elastic moduli; the tolerance for layer thickness required by this program was not met at this field site. For this reason typical back calculations of elastic moduli were not performed. FWD data was used to calculate Impulse Stiffness Modulus (ISM) values according to equation 4.1 (Bush, 1990). The ISM is defined as the load in kips divided by the center plate deflection in mils and is an indication of the overall pavement system stiffness. The ISMs developed for comparison purposes was an average of twenty-one tests in RAP and four tests in limerock at three different load levels, per testing cycle. Raw ISM data is shown in Appendix B. A plot of ISM for RAP and limerock versus time is shown in Figures 4.2 for the 9000-lbf tests. Also included in the plot are one standard deviation error bars. Plots for the 6000-lbf and 12000-lbf tests are shown in Appendix C.

Based on moisture content changes from week six to week eight, RAP proved to be less susceptible to moisture than limerock.

4.4 Clegg Impact Test

Twenty-four Clegg impact tests were conducted on RAP and nine were conducted on limerock per testing cycle. Each test consists of four drops of a 10-lb hammer over 18 inches. The Clegg Impact Value (CIV), which is the peak deceleration rate in tens of gravities, is obtained. All the CIV data collected during this investigation can be viewed in Appendix D. The graph of CIV versus time is shown in Figure 4.3. One standard deviation error bars are also included.

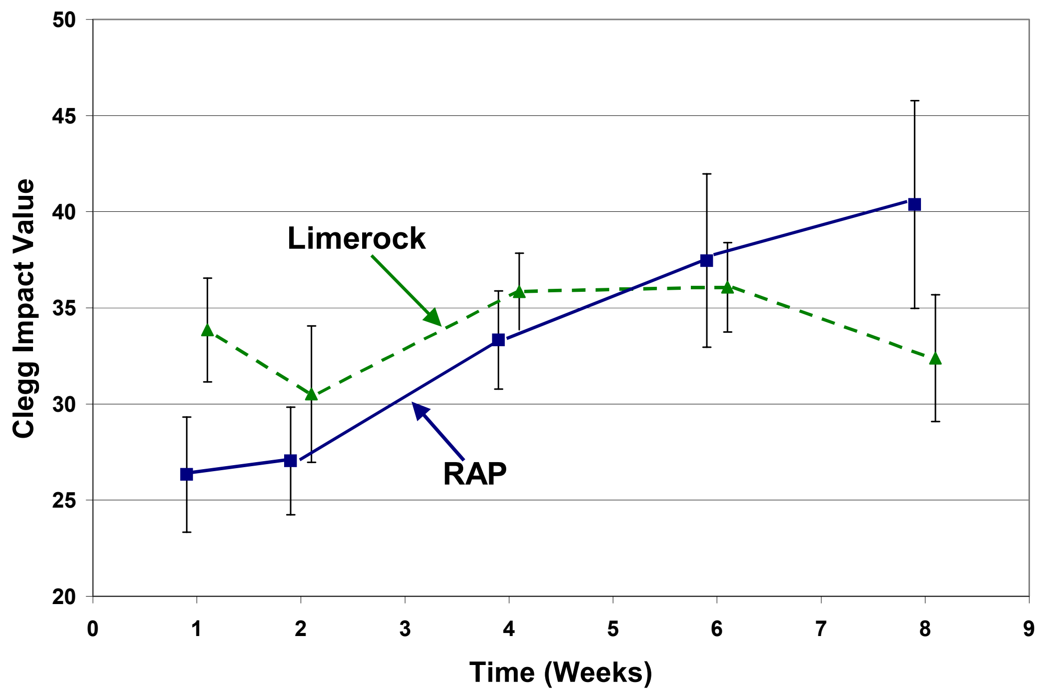

Figure 4.3 CIV vs. Time for RAP and Limerock

The CIV for limerock is higher than the CIV for RAP for four out of the five test intervals. The strength of RAP is steadily increasing over time based on the CIV. Again it can be seen that the strength of the limerock decreases between the sixth and eighth week. The limerock undergoes a 4% loss of CIV between during this period. Week one testing showed that the limerock was 28% stiffer than the RAP. Week two, week four and week six tests show the limerock as being 18%, 13%, and 4% stronger than RAP respectively. As time passes RAP's strength nears that of limerock, finally surpassing it during week eight. Using the CIV as an indicator, after eight weeks the RAP has become 55% stronger whereas the limerock has become 4% weaker. RAP has a large strength gain compared to relatively small strength gains seen in the limerock over the eight-week period. Based on the error bars it can be concluded that there is no change in the CIVs for limerock however, there is a definite increase in RAP CIVs over eight weeks. This research indicates that RAP is again less susceptible to moisture than limerock.

4.5 Soil Stiffness Gauge

Thirty-three Soil Stiffness Gauge tests were completed each test cycle, twenty-four on RAP and nine on limerock. At each test location three SSG tests were performed, the tests were centered around the location of the Nuclear Densometer tests. The average of all three tests were taken to establish a stiffness value for each location. Figure 4.4 presents the trends in stiffness values throughout the eight-week testing cycle. Included in the plot are one standard deviation error bars.

4.6 Field Limerock Bearing Ratio

Eight Limerock Bearing Ratio (LBR) tests were conducted on the RAP and three were conducted on the limerock each test interval. Figure 4.5 depicts the trends in LBR values throughout the first eight weeks following construction. Following construction the LBR values for RAP and limerock were 22 and 87 respectively. Throughout the eight weeks RAP never achieved an LBR value greater than 43. Limerock attained LBR values slightly greater than 100 during the week four and week six testing intervals. Following this peak period the LBR for limerock decreased by 38% due to moisture variations. From week one to week eight the LBR values of the RAP increased 55% as compared to a 31% decrease for the limerock, again indicating that RAP is less susceptible to moisture variations than limerock. Field LBR data is shown in Appendix F.

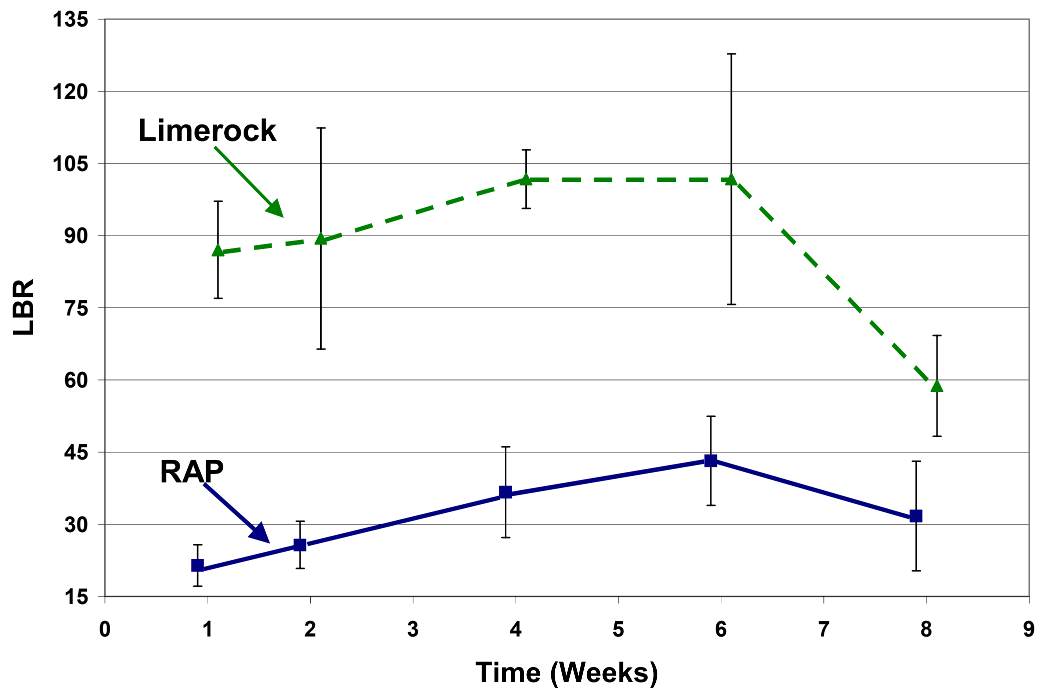

Figure 4.5 LBR vs. Time for RAP and Limerock

4.7 Comparisons Between Test Results

The previous sections showed the initial strength gains in RAP and limerock based on the FWD, Clegg, SSG, and LBR tests. In order to draw further conclusions from this data it was plotted as total percent increase versus test type, with the total increase being from week 1 to week 8. Figure 4.6 summarizes the strength variations from the field-testing at week eight.

4.8 Density and Moisture Tests

Densities and moisture contents were determined by test methods FM 1-T 238 and FM 5-507 respectively. Upon completion of the field site the dry density of RAP was 118 pcf (1.89 g/cm^3) and the dry density of limerock was 114 pcf (1.83 g/cm^3). The RAP achieved higher densities than the limerock throughout the testing cycle. Subsequent tests showed little change in the density of RAP or limerock. Density can be depicted in terms of relative compaction. Relative compaction is defined as the ratio of the field dry density to the laboratory maximum dry density according to a specified standard test such as the standard or modified Proctor (Holtz and Kovacs, 1981). Maximum laboratory dry densities of 117 pcf (1.87 g/cm^3) for the RAP (Doig, 2000) and 116 pcf (1.86 g/cm^{3}s) for the limerock (Central Testing Laboratory, 2001) were reported. The relationship between relative compaction and time is shown in Figure 4.8.

4.10 Temperature Profiles

Previous research by Rodriquez (2001), Doig (2000) and Montemayor (1998) suggest that a relationship exists between temperature and the behavior of RAP. In-situ temperature monitoring took place over the course of this investigation using VEMCO mini-log temperature probes. Temperature profiles for the RAP were developed using this data by averaging the data over the initial eight-week study period. The average temperature profile is shown in Figure 4.11. One standard deviation error bars are also included in the plot. The temperature gradient (ΔT/ ΔZ) decreases linearly. The average temperature of the RAP decreases from 95°F at the surface to 89°F at a depth of 30 inches.

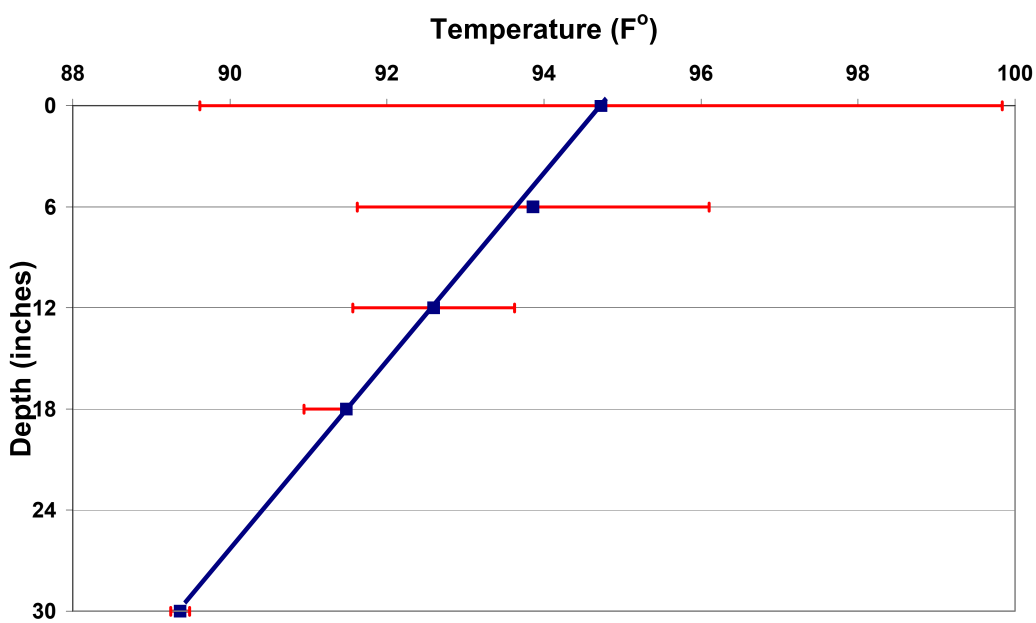

Figure 4.11 Average Temperature Profile for RAP (April 25 – June 14, 2001)

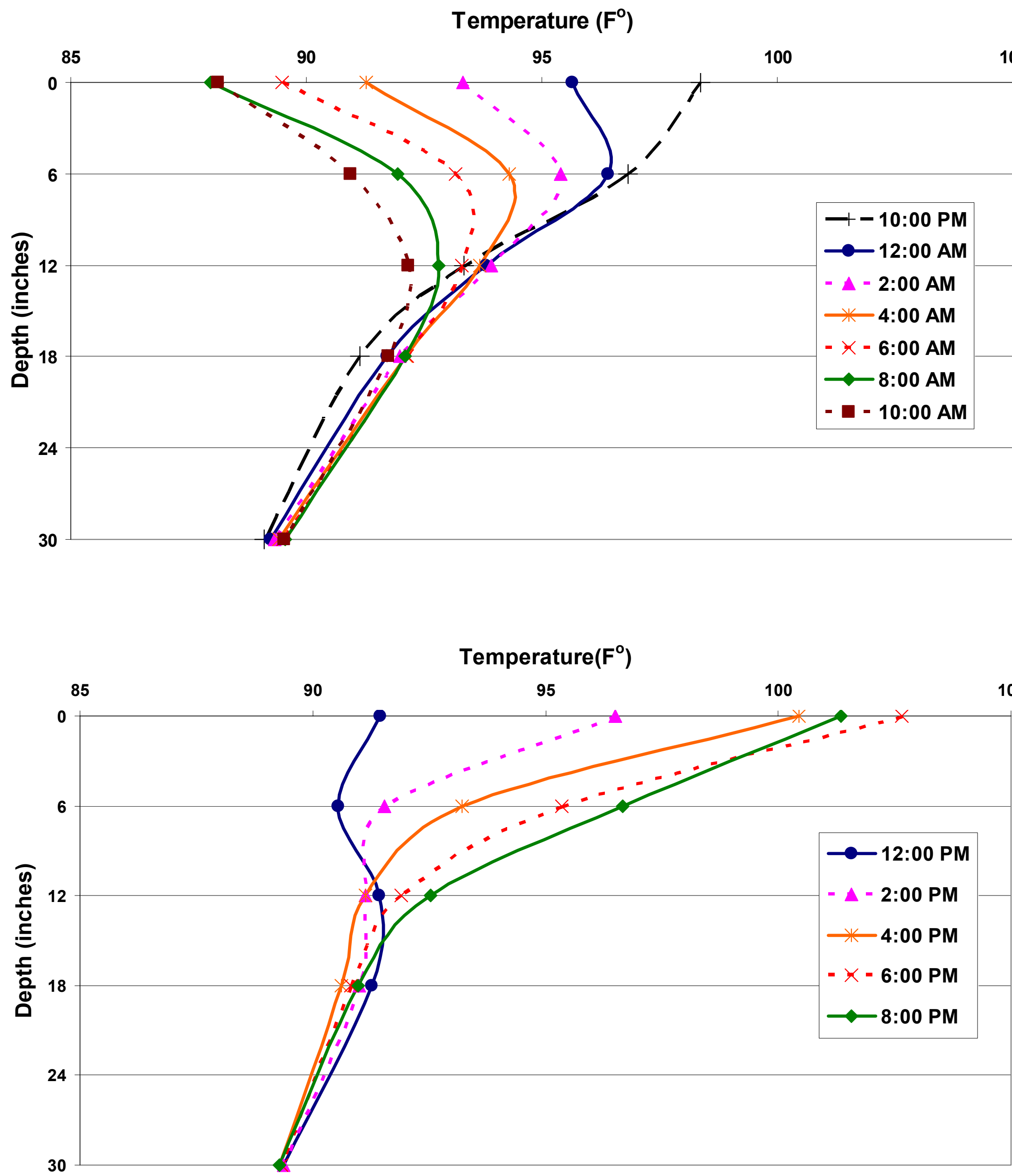

Figure 4.12 Bi-hourly Temperature Profiles for RAP (April 25–June 14, 2001)

4.11 Dry Rodded Unit Weight of RAP-Soil Mixtures

The relationship between unit weight and RAP-soil mixtures was initially evaluated through dry rodded unit weight tests. The objective of these tests was to characterize the effects of soil mixtures on the unit weight and use the results to aid in the selection of mixtures to be used for further investigation. This test was relatively quick and consumed less material as compared to standard compaction procedures. Tests were conducted starting with a sample of 100% RAP and incrementally adding the required amount of fine sand (i.e. material passing the #40 sieve size) to obtain the desired mix proportions. The results are shown in Figure 4.13. A maximum unit weight was achieved for a mixture of 80% RAP - 20% soil. The unit weight was improved by approximately 7 lb/ft^3 or 7.5% from a 100 to an 80% RAP sample, and 3.4 lb/ft^3 from a 60 to 80% RAP sample. The largest changes in unit weight occurred for samples containing 60 to 70 and 100 to 85 percent RAP, while minimal changes in unit weight occurred for mixtures containing 70 to 85 percent RAP. Based on these findings, RAP-soil mixtures containing 60, 80, and 100% RAP were selected for further investigation. A mixture yielding a maximum density was achieved for an 80% RAP mixture and the 60% RAP mixture was selected to investigate the behavior of RAP-soil mixtures over a broader range. Additional investigation of mixtures from 0 to 60% RAP were considered to be unnecessary as a secondary objective was to utilize the maximum amount of RAP. The sample preparation procedure for the fine sand also proved to be very time consuming and labor intensive.

The maximum densities achieved for each mixture follow a similar trend as reported for the results obtained from the dry rodded unit weight tests (Figure 4.13). The 80% RAP mixture yielded the maximum density, followed by the 60% RAP mixture and the 100% RAP respectively.

The relationship between maximum dry unit weight and the percent material passing the #40 sieve size present in the RAP-soil mixtures is presented in Figure 4.22. Since the RAP-soil mixtures attained a maximum dry unit weight at 80% RAP, the optimal percent passing to achieve maximum density for the mixtures tested is about 35% for the #40 sieve size. An increase in the material passing the #40 sieve size increased the density until an optimal level was achieved; further increase caused a slight decrease in density. Changes in density were more pronounced below the optimal percent passing (i.e. 35%) the #40 sieve size.

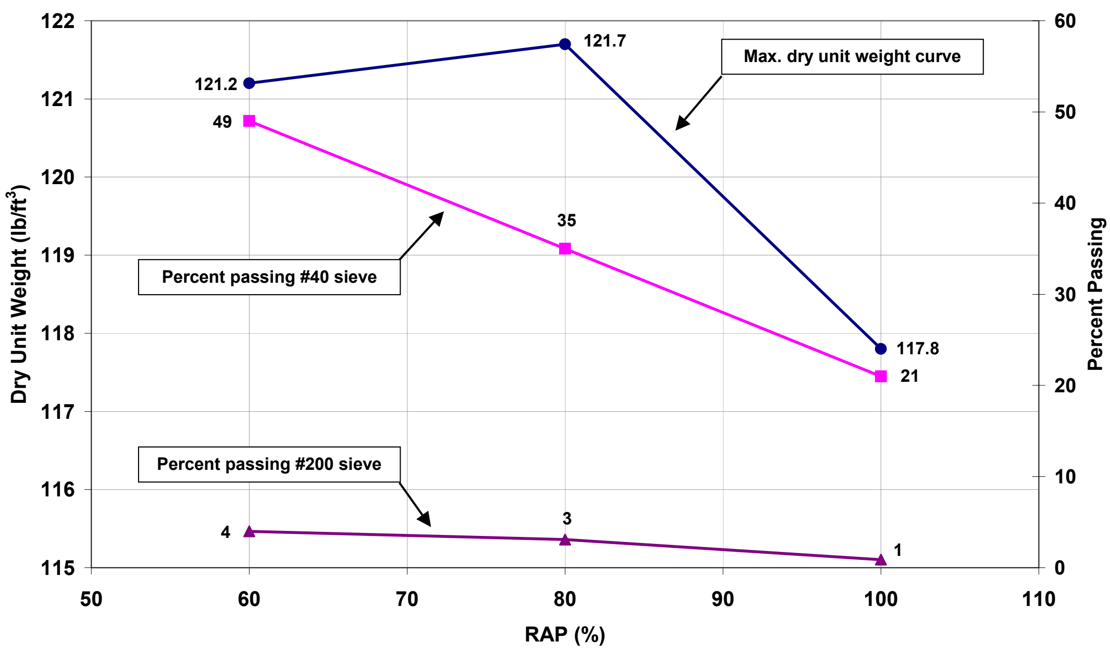

Figure 4.22. Dry unit weight – gradation relationship of RAP-soil mixtures

4.13.2 Permeability

The permeability test results for the RAP and RAP-soil mixtures are presented in Figure 4.23. Permeability of the RAP and RAP-soil mixtures remained relatively constant with changes in hydraulic gradient. The average permeability of the 100, 80, and 60% RAP mixtures were $2.0x10^{-4}$, $3.1x10^{-5}$, and $1.8x10^{-6}$ cm/s respectively. Figure 4.24 shows the average permeability in relation to the RAP percentage in the mixtures. For the range examined, the permeability decreased approximately by one order of magnitude for each increment of added fine sand.

Casagrande and Fadum (1940) report a permeability of $1x10^{-4}$ cm/s as an approximate boundary between soils providing good and poor drainage under low hydraulic gradients. Based on this, RAP is classified as a material providing good drainage while the RAP-soil mixtures classify as a poorly drained soil. The amount of fines (material passing the #200 sieve) present affects the drainage characteristics of a material. Added fines fill the intergranular voids; reducing the effective pore size, thereby increasing friction and restricting flow through a material. The RAP and RAP-soil mixtures had between 1 to 4% material passing the #200 sieve as determined by dry sieve analysis. According to Barksdale (1991) a base material is not free draining if the amount of material passing the #200 sieve is more than about 2%. Investigation by Blanco et al. (2003) on the laboratory and in-situ permeability of base materials in Missouri revealed that the average permeability of the base materials were 1000 times lower than typically required for good drainage. The laboratory permeabilities ranged from $9x10^{-2}$ to $3x10^{-7}$ cm/s and the in-situ permeabilities ranged from $2x10^{-3}$ to $4x10^{-5}$ cm/s. Average values for the percent fines (material passing the #200 sieve) determined by the dry

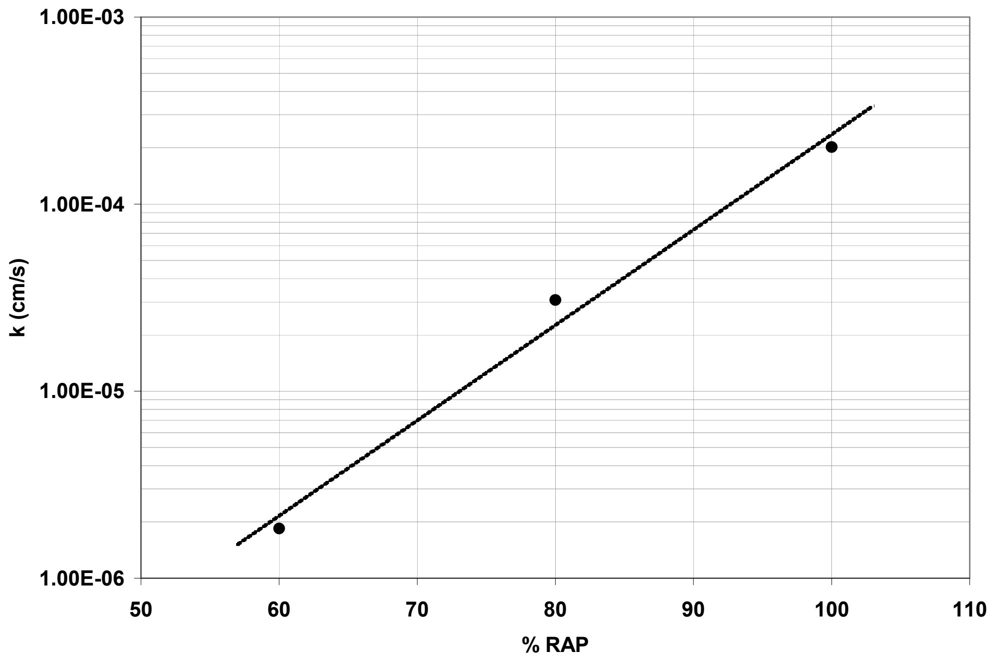

Figure 4.24 Permeability vs. percent RAP for RAP-soil mixtures

4.13.3 Limerock Bearing Ratio

Density is usually an indicator of the strength and stability of granular soil material. Densely compacted materials demonstrate higher strengths with less deformation than the same loosely compacted materials. The strength of the RAP-soil mixtures as measured by the LBR test are presented in Figures 4.25 and 4.26. LBR results of samples tested as base material are shown in Figure 4.25. All the samples tested were below the minimum LBR requirement of 100 for base material. The relative compaction of all base samples for LBR testing were close to 100 percent. The average density, LBR, and relative compaction are summarized in Table 4.4. The addition of fine sand resulted in an increase in density, but the most significant improvement was obtained in the LBR. The

4.13.4 Static Triaxial Compression

The strength of the RAP and RAP-soil mixtures was also measured by triaxial compression tests. Stress-strain curves were developed for each sample to determine the initial elastic modulus, secant elastic modulus, and maximum stress at failure. The initial modulus consists of the initial slope of the stress-strain curve and the secant modulus was determined from the slope of a straight line from the origin to 50% of the maximum stress level. The stress-strain characteristics of the RAP and RAP-soil mixtures are presented in Figures 4.27 and 4.28.

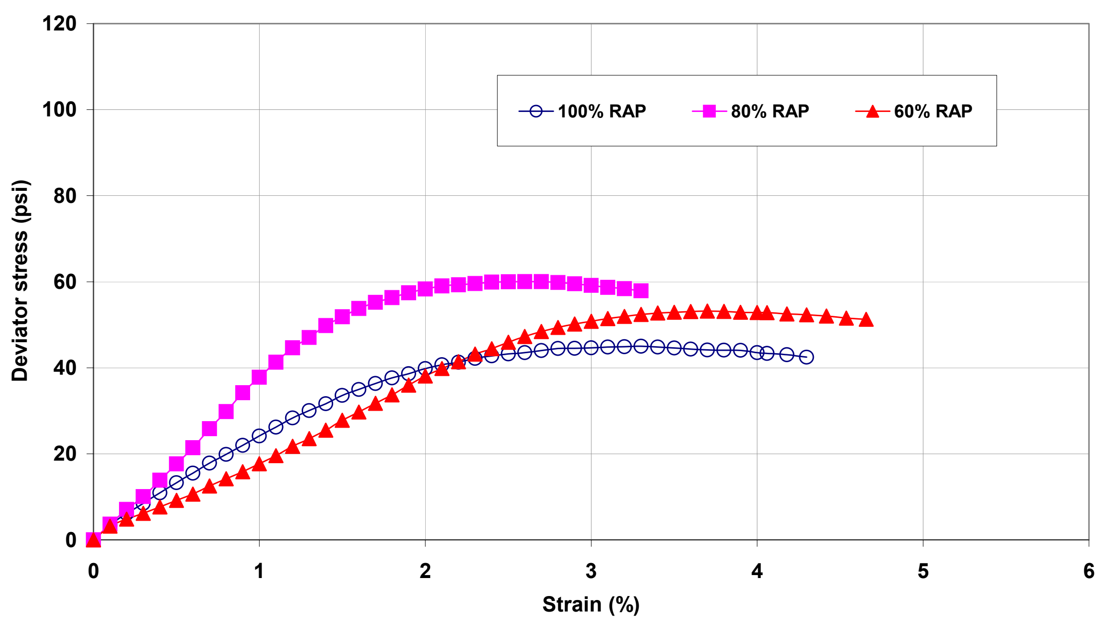

Figure 4.27 Stress-strain characteristics of RAP-soil mixtures at effective confining pressures of 5 psi

4.13.5 Resilient Modulus

The resilient modulus results of the RAP and RAP-soil mixtures tested as base and subgrade materials are presented in a logarithmic format in Figures 4.31 and 4.32 respectively. The results show that the 100% RAP specimens yielded the highest resilient modulus for the ranges of bulk stresses (θ) tested, followed by the 80 and 60% RAP mixtures. This behavior coincides with findings from Clary et al. (1997), Maher et al. (1997), and Bennert et al. (2000), where the resilient modulus increased as the percentage of RAP in the mixture increased. The resilient modulus also increased with an increase in bulk stress, which is typical of granular soils. The samples tested as base material showed very consistent results, with regression coefficients (r^2) ranging from 0.85 to 0.98. However, the results of samples tested as subgrade material were less consistent, with regression coefficients as low as 0.47 and 0.50 for the 80 and 100% RAP samples. The 60% RAP sample had a regression coefficient of 0.79, but the results were obtained by testing only one specimen due to material shortage. All the remaining results were obtained by performing 2 tests for each RAP and RAP-soil mixture tested as base and subgrade material. The regression constants, k_1 and k_2, derived from the test results fall within the ranges of typical values for base materials specified in the AASHTO *Guide for Design of Pavement Structures* (1993).

permanent deformation tests conducted on RAP, recycled concrete aggregate (RCA), and a dense-graded aggregate coarse (DGABC) by the Bennert et al. (2000), RAP obtained the highest permanent strain. The respective permanent strains of the RCA and DGABC were 6.9 and 12.0% the strain of RAP. Recall that the resilient modulus is defined as the deviator stress divided by the recoverable (resilient) strain. During the load sequences, RAP might experience larger plastic deformations and smaller resilient strains, while conventional material might undergo smaller plastic deformations with larger resilient strains. This would result in higher resilient modulus for RAP and lower resilient modulus for conventional materials. Despite the higher resilient modulus obtained for RAP, it is likely that based on the findings by Bennert et al. (2000), RAP would experience larger plastic deformations, showing potential for rutting and possible creep behavior.

4.13.6 Compaction Characteristics

A summary of the compaction characteristics of all the tests is presented in Appendix L. An effort was made to maintain the compactive effort as close as possible to modified Proctor energy (56,000 ft-lb/ft^3) and to perform compaction at the optimum moisture content for each RAP-soil mixture. The number of layers and the number of blows per layer for the static triaxial compression, resilient modulus, and permeability tests were modified to achieve a compactive effort as close as possible to 56,000 ft-lb/ft^3.

The relative compaction of the LBR RAP-soil mixtures was very consistent with values close to 100 percent. The decrease in sample size for the static triaxial compression, resilient modulus, and permeability tests, resulted in variations in the relative compaction values of the RAP-soil mixtures.

4.14 Preliminary Creep Investigation Results

The load-deflection versus time data was reduced to the plot shown in Figure 4.33. The data indicate all three materials experienced a rapid initial deflection increase followed by a leveling trend that was either horizontal or very close to horizontal. When comparing the 100% RAP to the 80/20 RAP-soil mixture, it is definite that the 80/20 RAP-Soil mix produced lower deflections. Both the RAP and RAP-soil mixture samples demonstrated a similar characteristic, in that they each displayed continuous deformation as shown in Figure 4.33. The A-3 soil, which was used as the control, stopped showing significant deformations after approximately 4000 minutes with an application of 33.5psi and after approximately 1000 minutes with an application of 67 psi. It should be noted that the A-3 soil sample exhibited a bearing capacity failure during the first minute of the 134 psi loading and it is therefore not possible to analyze the increments of 134 psi and 268 psi. When comparing the deformation patterns of the RAP samples to the A-3 soil, it is evident that the RAP samples exhibit much smaller initial deformations with continuous deformations. On the other hand, the A-3 soil exhibits much larger initial deformations, which quickly level off and nearly stop deforming.

To normalize the vertical axis of Figure 4.33, it was converted from deflection to an axial strain. This is a result of making assumptions in order to calculate the strain of each sample. This experiment was based on the LBR methodology where the mold diameter was 6 inches and the piston diameter was 1.95 inches. As a result, the strains are not one-dimensional. and strain cannot be calculated with exact certainty. In order to calculate a strain, it was assumed that the original height (h_o) for the strain ($\varepsilon=\Delta h/h_o$) was the height of the sample located directly underneath the piston. It was also assumed that all of the deformation (Δh) occurred in the column of soil located directly beneath the 1.95-inch piston.

4.15 Environmental Results and Discussion

4.15.1 Field Study

Using the surface water and leachate water sampled from the field site over a 10-month period, Silver, Cadmium, Chromium, Lead, and Selenium concentrations were determined versus time. Typically, eight metals are analyzed to determine their "*leachability*" into the environment; this includes the five above plus, Mercury, Arsenic and Barium. Mercury was not evaluated as it is a fairly volatile substance and most probably volatilized prior to the milling operation for RAP. Arsenic and Barium have historically not been present in the by-products from the asphalt industry and were not investigated by other researchers who evaluated RAP (Townsend and Brantley, 1998). Therefore, neither of these metals were included in this study.

The format used to present the results is consistent throughout this section. Both tables and figures are used for each element. The first column of the data tables shows the time-of-exposure, (i.e. the number of days after construction when aqueous samples were collected). The figures are semi-log plots that show the EPA Standards and the lowest detectable concentration for each of the five metals. The lowest detectable concentration was determined based on the range of concentrations expected for each metal. Statistical data from 3 standard tests were used to develop an expected range within which the AAS yields reliable data. Data above and below this range are not near a regression line developed based on the standards. During this research, only values below the detection limit occurred. These concentrations are shown so readers can visualize the total number of samples tested, along with those below the AAS detection limit.

4.15.1.1 Sampling Protocol

The sampling protocol for the surface water collection was slightly different than the protocol for the leachate collection. Following severe rainfall events, surface water samples were collected in two separate collection tanks (Figure 3.11). These samples were collected, analyzed and are reported in two separate columns within these tables. On many sampling days, there was insufficient quantity in the second collection tank for analyses. During sample collection, it was noted that the volume of surface runoff from the RAP collection system was larger than the volume produced by the limerock control site. This is probably attributed to more surface runoff in RAP than limerock.

As expected, the leachate sample volumes were lower than the surface water volumes, therefore, no single rainfall event, during the 10-months, generated enough leachate to require the 2^{nd} tank shown in Figure 3.11 for collection. Subsequently, only one column of the data table is presented for the leachate results.

Data shown in the tables represent the mean value of each analysis, which includes three replicates with less than 5% variation. Since all standard deviations were much less than the 5 % limit they were not displayed in the following tables. Data was also presented in graphical format, in Figures 4.34 – 4.38, to determine if there were any trends in the concentration changes over time during the study period. US EPA standards are also shown in each figure for comparison purposes. In many instances the data from the testing was below the detectable limit of the testing equipment for the particular chemical being analyzed. This value is also shown in the tables and on the plots.

4.15.1.2 Silver (Ag) Concentration in Runoff and Leachate Samples

Appendix Table J.1 shows the concentration of silver in surface runoff and leachate samples collected from both the RAP and Limerock collection systems. There were 14 sampling periods over 165 days that produced 50 adequate samples out of a possible 84. There were insufficient quantities retrieved for testing in the remaining 34 samples. Three tests were conducted on each of the 50 adequate samples and 25 sets of three, or 50 percent, produced results that were below the detectable limit of 1 µg/l for silver. The three tests conducted on each of the 27 adequate RAP samples produced 15 sets of three, or 56 percent, below the detectable limit. There were 23 adequate samples collected from the Limerock collection system, of which 10 sets of three, or 44 percent, were below the detectable limit.

The initial surface runoff samples from RAP site were collected after 38 days of exposure, and displayed a concentration below detection limit. The next sample was collected one week later with a concentration slightly above the detection limit. Detectable concentrations of silver from RAP surface runoff samples were found for those collected within 100 days of exposure. After 100 days of exposure, surface runoff samples from the RAP site showed no detectable concentrations of silver. As shown in Figure 4.32, concentrations of detectable silver in surface runoff samples from the RAP site were far below the EPA standards of 5,000 µg/l and just barely above the detectable limit. No change in concentration over time was observed during the sampling period. The results indicated that, with regard to silver, RAP possessed no threat to the environment through surface runoff.

The first detectable Ag concentration in the leachate from RAP was not found until 58 days of exposure, while the last detectable concentration was found in the samples collected after 134 days. While detectable, these samples produced very low Ag concentrations, which were slightly above detection limit and similar

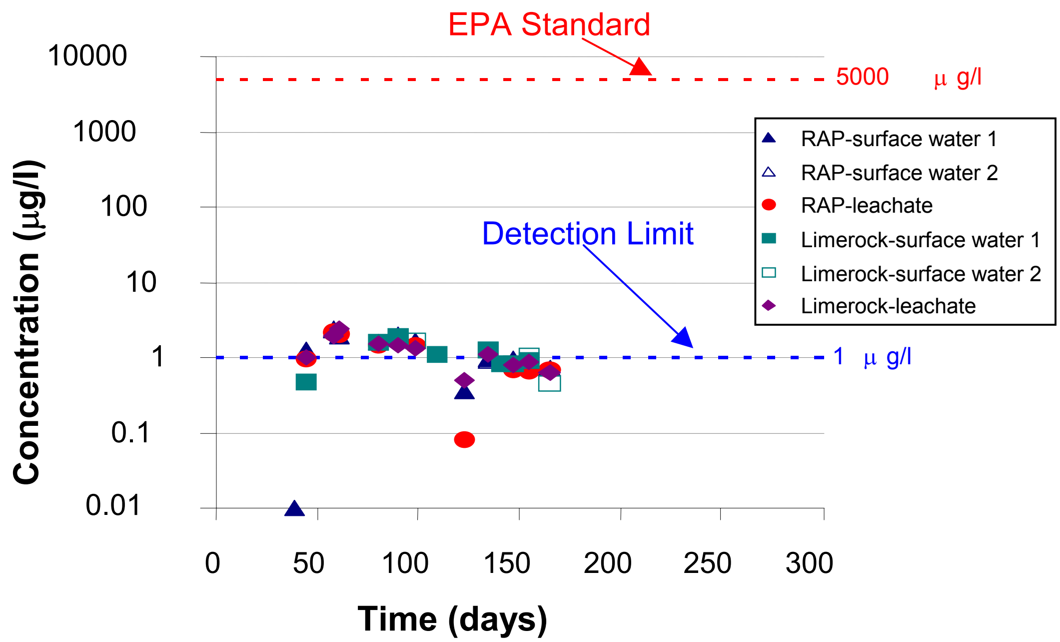

Figure 4.34. Silver (Ag) Concentration versus Time in Surface Runoff and Leachate Collected from the RAP and Limerock Collection Systems.

4.15.1.3 Cadmium (Cd) Concentrations in Runoff and Leachate Samples

Appendix Table J.2 and Figure 4.35 show the concentration of cadmium in surface runoff and leachate samples collected from both the RAP and Limerock collection systems. There were 14 sampling periods over 165 days, yielding data for 50 adequate samples out of a possible 84. There were insufficient quantities retrieved for testing in the remaining 34 samples. Three tests were conducted on each of the 50 samples and 47, or 94 percent, produced results below the detectable limit of 1 µg/l for cadmium. The three tests conducted on each of the 27 adequate RAP samples produced 26, or 91 percent, below the detectable limit. There were 23 adequate samples collected from the Limerock collection system, of which 21, or 91 percent, were below the detectable limit.

Appendix Table J.2 shows the concentration of cadmium in surface runoff and leachate samples collected on site. The first surface runoff samples from the

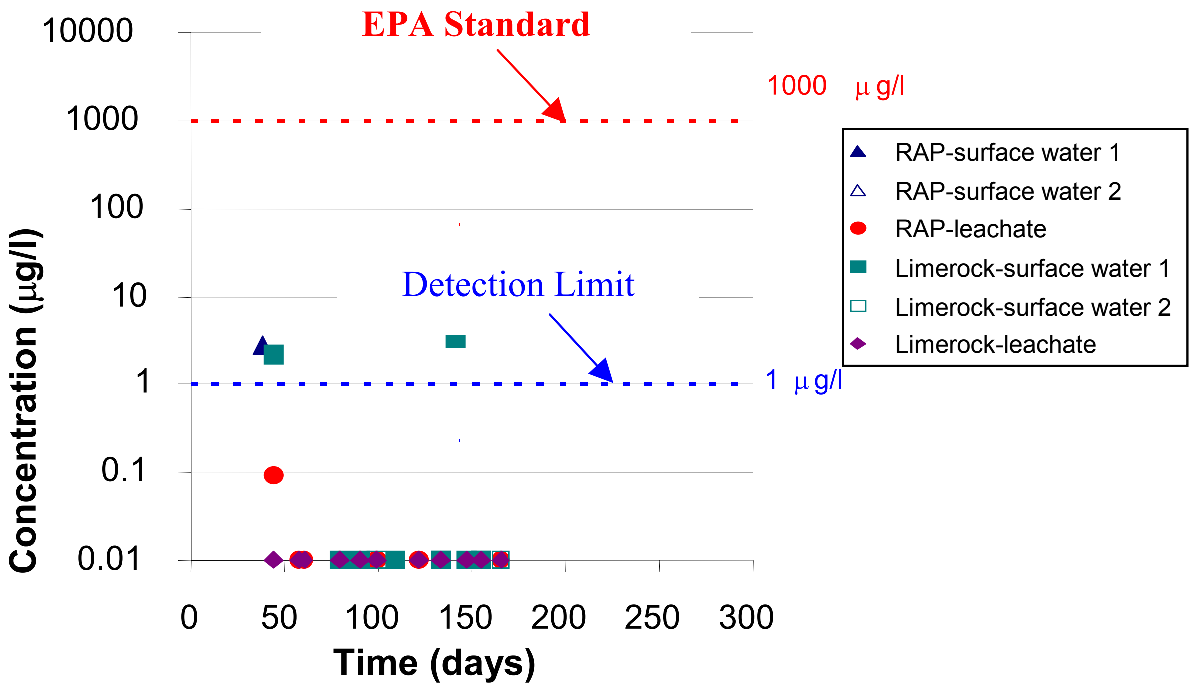

Figure 4.35 Cadmium (Cd) Concentration versus Time in Surface Runoff and Leachate Collected from the RAP and Limerock Collection Systems.

4.15.1.4 Chromium (Cr) Concentrations in Runoff and Leachate Samples

Appendix Table J.3 and Figure 4.36 show the concentration of chromium in surface runoff and leachate samples collected on site. There were 14 sampling periods over 165 days, yielding data for 50 adequate samples out of a possible 84. There were insufficient quantities retrieved for testing in the remaining 34 samples. Three tests were conducted on each of the 50 samples and 49, or 98 percent, produced results below the detectable limit of 5 µg/l for chromium. There were 27 adequate samples collected from the RAP collection system and all were below the detectable limit. There were 23 adequate samples collected from the Limerock collection system, of which 22, or 96 percent, were below the detectable limit.

4.15.1.5 Lead (Pb) Concentrations in Runoff and Leachate Samples

Appendix Table J.4 and Figure 4.37 show the concentrations of lead in surface runoff and leachate samples collected on site. There were 17 sampling periods over 290 days, yielding data for 65 adequate samples out of a possible 102. There were insufficient quantities retrieved for testing in the remaining 37 samples. Three tests were conducted on each of the 65 samples and 54, or 83 percent, produced results that were below the detectable limit of 5 μg/l for lead. The three tests conducted on each of the 36 adequate RAP samples produced 32 sets, or 89 percent, below the detectable limit. There were 29 adequate samples collected from the Limerock collection system, of which 22 sets, or 76 percent, were below the detectable limit.

The first surface runoff samples from the RAP site were collected after 38 days of exposure and displayed a concentration of about 39 μg/l. The second detectable concentration of lead was found in the sample on the 61st exposure day displaying a concentration about 335 μg/l. It was not until 165-day of exposure when a third detectable concentration of lead (21 μg/l) was again found in the surface runoff sample. Concentrations above the detectable limit were only found in samples obtained from the 1st tank of the surface runoff collection system. It was concluded that the three spikes in the lead concentrations within the RAP resulted from external sources. Possible sources could be the vehicular traffic on the pavement prior to recycling such as a wheel balance weight or could be naturally occurring in the aggregate used in the asphalt mix from which the RAP comes.

The only detectable concentration of lead in leachate from the RAP site was found from the sample obtained on the 58th exposure day which displayed a concentration of 7.76 μg/l, slightly above the detection limit of 5 μg/l, and far below EPA lead standard of 5,000 μg/l. The remaining leachate samples showed no detectable concentrations of lead.

4.15.1.6 Selenium (Se) Concentrations in Runoff and Leachate Samples

Appendix Table J.5 and Figure 4.38 show the concentration of selenium in surface runoff and leachate samples collected on site. There were 14 sampling periods over 165 days, yielding data for 50 adequate samples out of a possible 84. There were insufficient quantities retrieved for testing in the remaining 34 samples. Three tests were conducted on each of the 50 samples and 9, or 18 percent, produced results that were below the detectable limit of 1 μg/l for selenium. Three tests were conducted on each of the 27 RAP samples and 9, or 33 percent, produced results that were below the detectable limit of 1 μg/l for selenium. All 23 samples obtained from the Limerock collection system produced results above detectable limit of 1 μg/l for selenium.

Several RAP surface runoff samples produced selenium concentrations just above the detection limit of 1 μg/l. Samples were retrieved from both the 1st and 2nd tanks for the 134th exposure day. Samples from the 2nd surface runoff tank had detectable concentrations, while samples from the 1st tank had no detectable concentration. This anomaly was assumed to be the result of some unknown source of selenium, which was present in the 2nd tank.

Leachate samples from the RAP site produced one slightly elevated selenium concentration. This outlier occurred for the sample retrieved at day 44. All remaining data, except one, showed detectable concentrations slightly higher or near to the detection limit. The high value of 85 μg/l at day 44, was still well below the EPA standard of 1000 μg/l. It was assumed to be the result of an unknown source of selenium.

Limerock surface runoff samples produced an average selenium concentration of 19.37 mg/l, which is well below the EPA Standard of. Samples were retrieved from both the 1st and 2nd surface runoff tanks.

Leachate samples from the RAP site produced elevated selenium concentrations. Although the average throughout the study was 426.53 μg/l, a

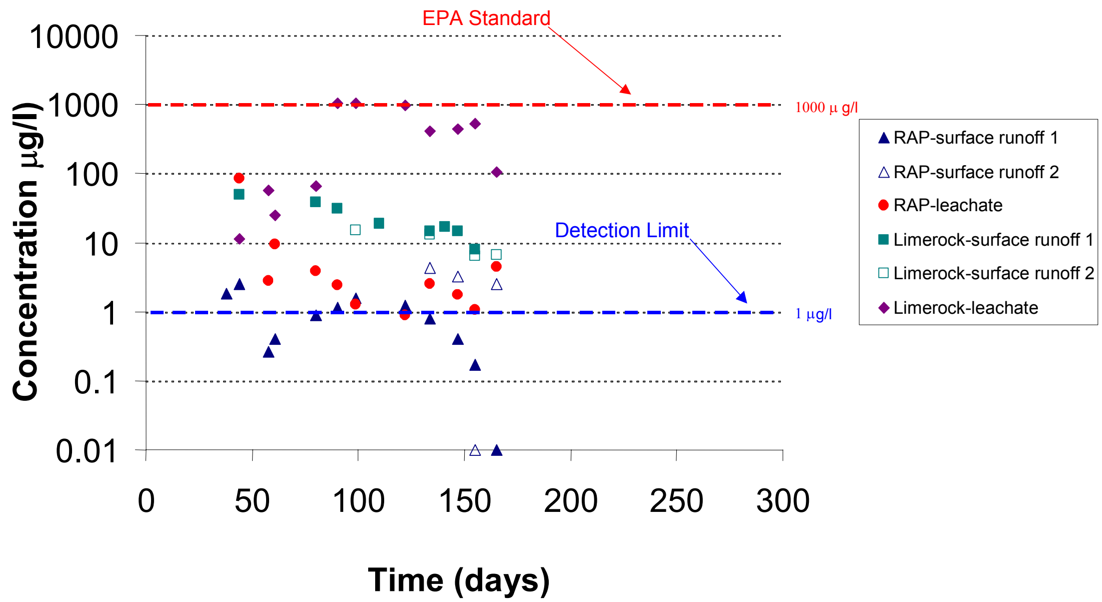

Figure 4.38 Selenium (Se) Concentration versus Time in Surface Runoff and Leachate Collected from the RAP and Limerock Collection Systems.

4.15.2 Laboratory Studies

4.15.2.1 TCLP and SPLP Tests

Laboratory TCLP tests conducted on RAP and limerock according to EPA methods showed that concentrations of silver (Ag), cadmium (Cd), and chromium (Cr) were not detectable (Table 4.11). As was the case for all environmental testing, three trials were performed on each sample and an average was determined. This process yielded a total of 30 trials on the RAP and Limerock samples. Of the 30 trials, 22 or 73 percent yielded results below the detectable limit. All of the TCLP and SPLP results above the detectable limit were well below the EPA Standards

4.15.2.5 Selenium

Appendix Table J.8 and Figure 4.41 show the concentrations of selenium in column leaching tests. When DDW was introduced to the RAP columns, two detectable concentrations were found in each of the duplicated columns near the detection limit. When SAR was introduced, no detectable concentrations were found. The results indicate that selenium leachate from RAP, when in contact with aqueous solutions of either DDW or SAR, has no significant effect on the environment.

When DDW was introduced to the Limerock columns, concentrations in excess of the EPA Standard were found. These concentrations generally decreased with time of exposure (Appendix Table J.8). As was stated previously, Selenium occurs naturally in sedimentary deposits. Because there was no information available on the source, storage and process of the Limerock used in this study, it is not possible to determine the cause of these high concentrations. Determination of this value was beyond the scope of the project.

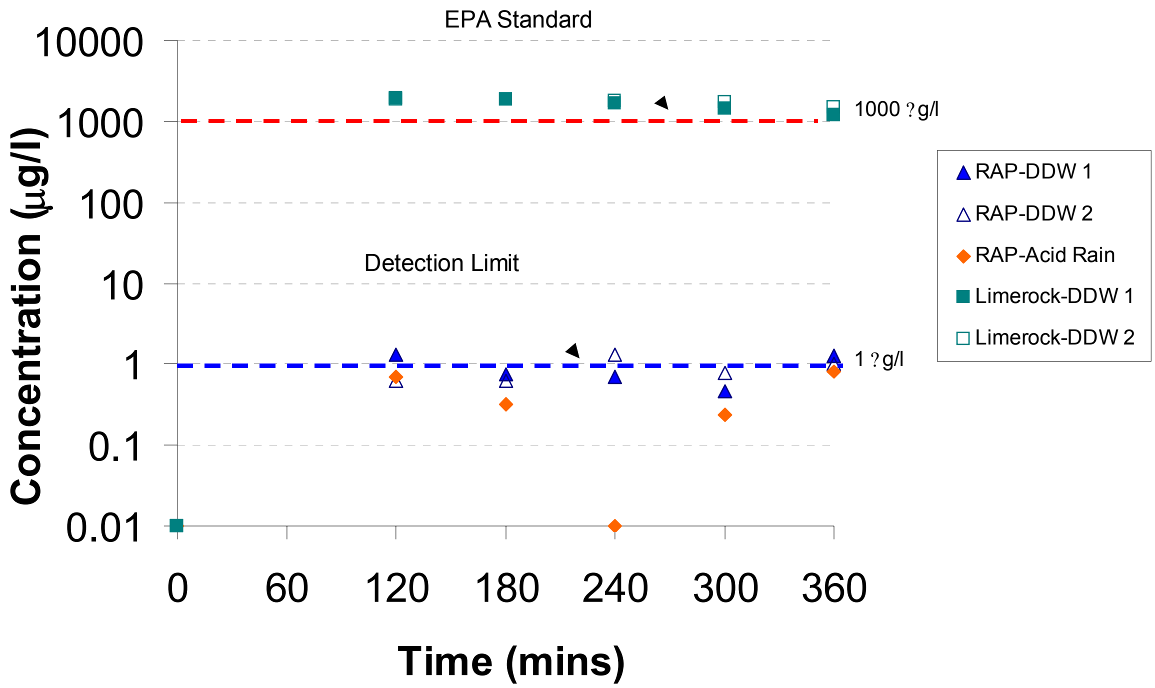

Figure 4.41 Concentration of Selenium in Leachate from Column Leaching Tests

4.15.3 Environmental Summary

Tables 4.13 and 4.14 present a summary of the testing for both RAP and Limerock, respectively. The data presented in the tables are the average concentrations for the data above the detection limit along with the percent of samples that produced data below the detectable limit of the lab equipment. Evaluation of the data in these tables indicates that RAP does not pose any threat to the environment, and that most of the data even falls below the detection limit of the equipment used. Concentrations as high as 10 µg/l were rarely observed showing how safe these materials are from an environmental standpoint.

Data in Table 4.13 indicates shows that none of the chemicals leach into the environment from RAP at significant levels regardless of the type of test

5. Conclusions

5.1 Initial Strength Gain Conclusions

Field testing to document the initial change in the engineering behavior of RAP based on strength and stiffness characteristics from the LBR, Clegg, FWD and SSG tests yielded the following conclusions.

1. FWD, Clegg, and SSG results consistently modeled the initial strength gains at lower strain levels, while the LBR values determined from field CBR’s reflect its strength at higher strains.
2. The strength-deformation characteristics of RAP increased with time after placement over the eight-week testing period while the limerock strength-deformation characteristics varied due to moisture changes, therefore, RAP was less susceptible to moisture than limerock.
    a) LBR, Clegg, and FWD test results showed a 50% increase in the engineering properties of RAP at week eight.
    b) SSG test results indicate a 15% increase in the stiffness of RAP at week eight.
3. The LBR testing procedure yields strength-deformation characteristics of RAP that are one-third those produced by the Clegg, FWD, and SSG.
4. Based on the small strain stiffness results of the Clegg, FWD, and SSG testing, RAP performed in a manner similar to limerock.

Therefore, RAP usage should be limited to subgrade applications or to sub-base applications below rigid pavements once the concerns over creep potential, or large strain, are clarified

5. Comparisons of RAP to limerock behavior using the Clegg, FWD, and SSG show that RAP achieved 80 to 115 % the stiffness of limerock during the eight-week testing intervals. Thus, the Clegg, FWD and SSG tests indicate that RAP is equivalent in stiffness to limerock.

5.2 RAP-Soil Mixing Conclusions

Laboratory testing to document the strength and drainage characteristics of RAP-soil mixtures lead to the following conclusions.

1. The addition of fine sand (i.e. material passing the #40 sieve) to RAP provided an improvement in density, bearing strength, and stiffness.
    a. The density and LBR improved with the addition of material passing the #40 sieve over the ranges examined in this study. The 80% RAP – 20% soil mixture provided significant improvements in density and strength characteristics. The 60% RAP – 40% soil mixture yielded better density and strength characteristics than 100% RAP.
    b. The major improvements in LBR are due to the added material passing the #40 sieve size, and not because of slight increases in density.
    c. Significant increase in the secant modulus was only achieved for the 80% RAP- 20% soil mixture.

5.3 Environmental Conclusions

Both the laboratory and field investigations indicate that the use of RAP as a highway fill poses no environmental concerns. Concentrations reported for the heavy metals evaluated in RAP (i.e., Silver, Cadmium, Chromium, Lead and Selenium) are well below all EPA Standards.

The testing protocol, which included four types of environmental evaluations, resulted in similar conclusions indicating these tests were properly conducted. With the exception of Selenium in Limerock, all metals evaluated yielded similar environmental properties in both the RAP and the limerock control. Selenium occurs naturally in many geologic deposits and influences the concentration in limerock.

6. Recommendations

RAP has proven to be a very useful highway fill material. The following recommendations address the several areas of concern that still exist.

1. The long-term strength deformation (i.e., creep or large strain) behavior of RAP and RAP-soil mixes should be investigated. Soils selected for mixing with RAP should increase the percentage of material passing the #40 sieve. Both laboratory and field tests should be conducted. To evaluate the long-term behavior, the FDOT Materials Office test pits in Gainesville, Florida should be used and the testing protocol outlined in the FDOT Materials Manual (2000) should be followed.
2. The correlations between LBR and dynamic tests such as the Clegg, FWD, or SSG should be developed from several field sites around the state. Based on results to date it is believed that the Clegg test best represents the strength-deformation characteristics of RAP and would be the recommended choice. Static and dynamic plate testing could be performed in conjunction with the Clegg tests at FDOT's Materials Office to develop correlations between the CIV and the modulus of subgrade reaction.
3. Following the research on the long-term strength-deformation characteristics, a full-scale highway study using RAP in sub-base, subgrade and general fill applications should be conducted. The study site should be at least ½ mile long. RAP should be compared to the other FDOT approved materials.

7. Field Specifications

The following specifications, presented in the Phase I report in the format currently used in the FDOT Specifications for Road and Bridge Construction, were modified to reflect the results from the Phase II findings. They are to be considered preliminary or developmental at this point and will be refined further during future research that will focus on the field and creep behavior of RAP and RAP-Soil mixes.

Special comments are included in this section to substantiate the reasons for the specifications. All comments are shown in italics. These specifications are presented for inclusion in two sections of the Florida Department of Transportation Standard Specifications for Road and Bridge Construction. One portion will be included in the section in Division II, under Construction Details for Base Courses as Section 283 and the other portion will be specified under the section in Division III, under Flexible Pavement Materials in Section 918.

SECTION 283

RECLAIMED ASPHALT PAVEMENT SUB-BASE

RAP is limited to sub-base applications below rigid pavements because of its excellent drainage characteristics, low LBR values, and potential for creep.

283-1 Description.

Construct a sub-base course comprised of reclaimed asphalt pavement (RAP) material below rigid pavement.

8. References

Alavi, S., Merport, T., Wilson, T., Groeger, J., and Lopez, A. (1997) *LTTP Materials Characterization Program: Resilient Modulus of Unbound Materials (LTTP Protocol P46) Laboratory Startup and Quality Control Procedure.* Federal Highway Administration Report No. FHWA-RD-96-176. January.

American Association of State Highway and Transportation Officials. (1993) *AASHTO Guide for Design of Pavement Structures.*

Ahrens, D. (2001). Essentials of Meteorology an Invitation to the Atmosphere. Wadsworth Group. Pacific Grove, California .

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ASTM Standard Method, (2002) Annual Book of ASTM Standards, American Society for Testing and Materials, 04.08 pp. 1010-1031.

Barksdale, R.D. (1991) *The Aggregate Handbook.* Washington D.C.: National Stone Association.

Appendix A

Field Moisture and Density Data

Appendix B

Falling Weight Deflectometer Data

Appendix C

6000-lbf and 12000-lbf

ISM vs. Time Plots

Appendix D

Clegg Impact Test Data

Appendix E

Soil Stiffness Gauge Data

Appendix F

LBR From Field CBR Data

Appendix G

Temperature Correlations

Appendix H

RAP-Soil Mixtures Laboratory LBR Data

LBR Data Sheet

Description of Soil	100% RAP (3) @ woptimum = 8%	**Date**	6/4/2002 (mixed)
			6/5/2002 (compacted)
Tested By	Francis & Eric		6/7/2002 (tested)
Compaction	Modified - Method D		
Comments	Sample was tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	9		10	
Mass of Can	0.0964	lb	0.1470	lb
Mass of Wet Soil & Can	0.9258	lb	0.8208	lb
Mass of Dry Soil & Can	0.8654	lb	0.7726	lb
Mass of Dry Soil	0.769	lb	0.6256	lb
Mass of Water	0.0604	lb	0.0482	lb
w (%)	7.85		7.70	
Average w (%)	7.78		St Dev =	0.106

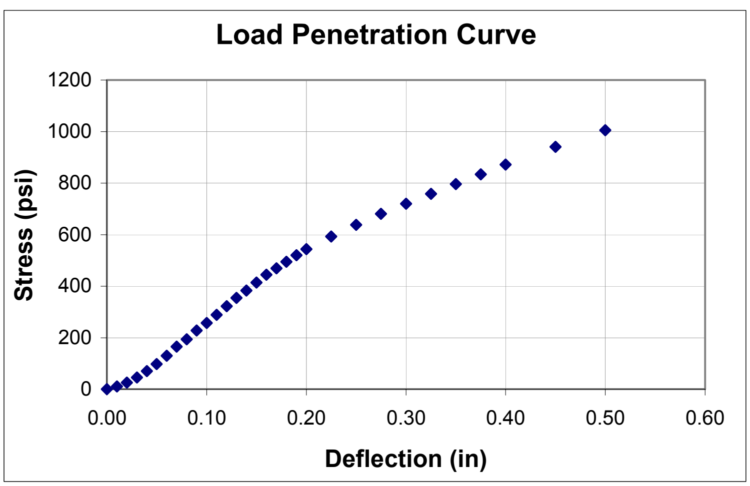
Density Computations

Mass of Mold	9.260	lb
Mass of Mold and Wet Soil	18.795	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.535	lb
Wet Density	127.1	lb/ft^3
Dry Density	117.9	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	10.0	30
0.020	25.4	76
0.030	45.2	135
0.040	69.6	208
0.050	97.4	291
0.060	129.9	388
0.070	165.1	493
0.080	193.5	578
0.090	228.0	681
0.100	257.5	769
0.110	288.6	862
0.120	322.1	962
0.130	354.3	1058
0.140	383.1	1144
0.150	414.5	1238
0.160	444.0	1326
0.170	469.4	1402
0.180	494.9	1478
0.190	519.7	1552
0.200	544.1	1625
0.225	593.3	1772
0.250	638.2	1906
0.275	680.4	2032
0.300	719.6	2149
0.325	758.4	2265
0.350	796.3	2378
0.375	833.8	2490
0.400	871.9	2604
0.450	941.2	2811
0.500	1005.5	3003



LBR 40

LBR Data Sheet

Description of Soil 100% RAP (4) @ woptimum = 8%

Date 6/10/2002 (mixed)
6/11/2002 (compacted)
6/13/2002 (tested)

Tested By Francis & Eric

Compaction Modified - Method D

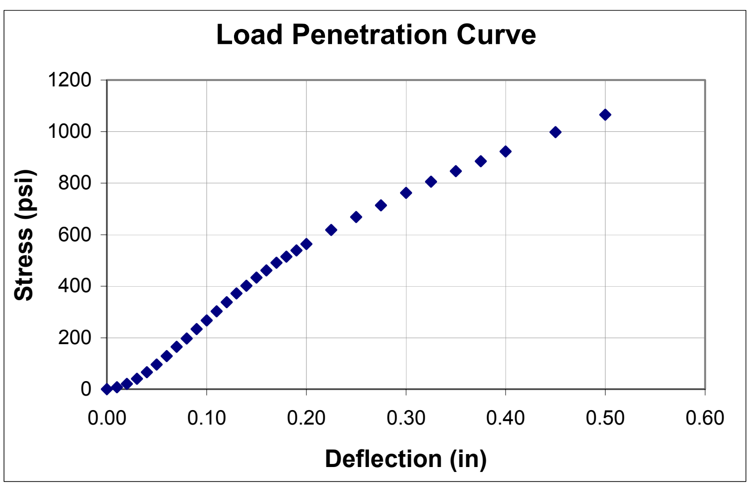
Comments Sample was tested as a base material (no surcharge)

Compaction Moisture Content				
Can Number	5		6	
Mass of Can	0.1248	lb	0.1574	lb
Mass of Wet Soil & Can	0.8888	lb	0.9128	lb
Mass of Dry Soil & Can	0.8334	lb	0.8656	lb
Mass of Dry Soil	0.7086	lb	0.7082	lb
Mass of Water	0.0554	lb	0.0472	lb
w (%)	7.82		6.66	
Average w (%)	7.24		St Dev =	0.816

Density Computations		
Mass of Mold	9.259	lb
Mass of Mold and Wet Soil	18.791	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.532	lb
Wet Density	127.1	lb/ft^3
Dry Density	118.5	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	7.4	22
0.020	21.1	63
0.030	40.5	121
0.040	66.3	198
0.050	95.1	284
0.060	128.9	385
0.070	164.1	490
0.080	196.9	588
0.090	233.7	698
0.100	266.5	796
0.110	302.7	904
0.120	337.5	1008
0.130	371.3	1109
0.140	401.8	1200
0.150	433.3	1294
0.160	461.1	1377
0.170	490.9	1466
0.180	514.3	1536
0.190	539.1	1610
0.200	563.5	1683
0.225	618.5	1847
0.250	668.3	1996
0.275	714.2	2133
0.300	761.8	2275
0.325	806.0	2407
0.350	846.5	2528
0.375	884.7	2642
0.400	922.8	2756
0.450	997.8	2980
0.500	1065.5	3182



LBR 44.6

LBR Data Sheet

Description of Soil	80% RAP (1) @ woptimum = 6%	**Date**	6/18/2002 (mixed)
			6/19/2002 (compacted)
Tested By	Francis		6/21/2002 (tested)
Compaction	Modified - Method D		
Comments	Sample was tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	3		4	
Mass of Can	0.3092	lb	0.1518	lb
Mass of Wet Soil & Can	1.0542	lb	0.8292	lb
Mass of Dry Soil & Can	1.0100	lb	0.7928	lb
Mass of Dry Soil	0.7008	lb	0.641	lb
Mass of Water	0.0442	lb	0.0364	lb
w (%)	6.31		5.68	
Average w (%)	5.99		St Dev =	0.444

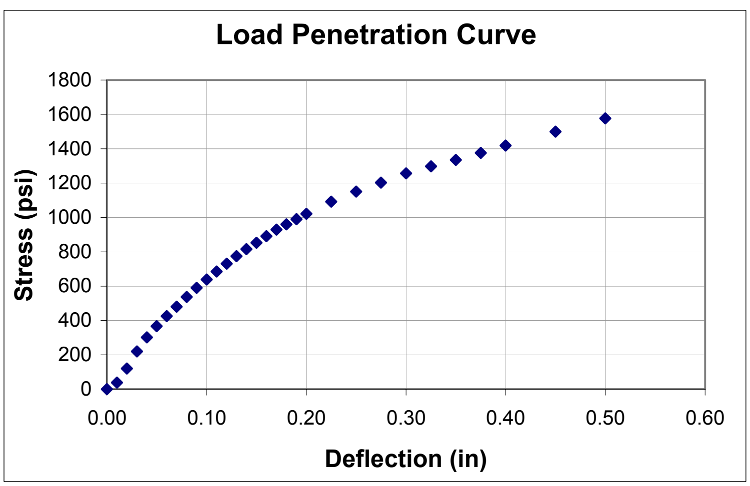
Density Computations

Mass of Mold	9.295	lb
Mass of Mold and Wet Soil	19.025	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.7305	lb
Wet Density	129.7	lb/ft^3
Dry Density	122.4	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	38.2	114
0.020	120.2	359
0.030	219.3	655
0.040	302.7	904
0.050	367.3	1097
0.060	424.9	1269
0.070	480.2	1434
0.080	537.4	1605
0.090	590.7	1764
0.100	638.2	1906
0.110	685.1	2046
0.120	730.0	2180
0.130	774.8	2314
0.140	815.3	2435
0.150	853.2	2548
0.160	891.4	2662
0.170	928.5	2773
0.180	960.0	2867
0.190	990.5	2958
0.200	1020.9	3049
0.225	1092.3	3262
0.250	1150.9	3437
0.275	1203.1	3593
0.300	1256.3	3752
0.325	1297.9	3876
0.350	1335.0	3987
0.375	1376.5	4111
0.400	1419.1	4238
0.450	1499.4	4478
0.500	1577.4	4711



LBR 85

LBR Data Sheet

Description of Soil 80% RAP (2) @ woptimum = 6%

Tested By Francis

Compaction Modified - Method D

Comments Sample was tested as a base material (no surcharge)

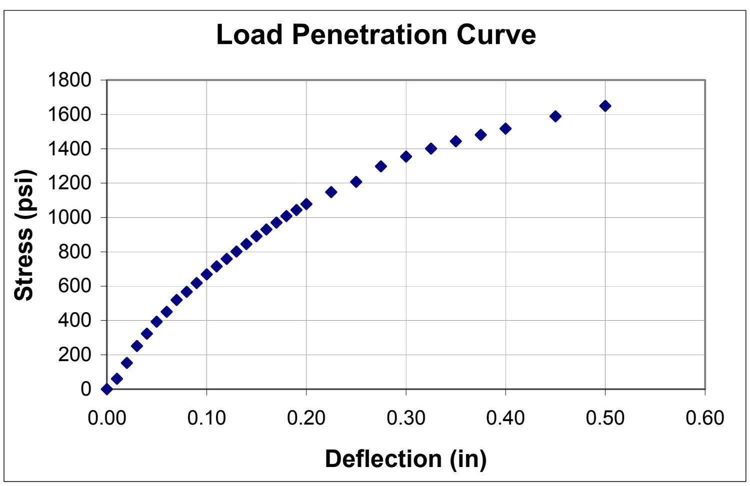
Date 6/18/2002 (mixed)
6/19/2002 (compacted)
6/21/2002 (tested)

Compaction Moisture Content				
Can Number	5		6	
Mass of Can	0.1248	lb	0.1575	lb
Mass of Wet Soil & Can	0.9854	lb	1.0446	lb
Mass of Dry Soil & Can	0.9350	lb	0.9942	lb
Mass of Dry Soil	0.8102	lb	0.8367	lb
Mass of Water	0.0504	lb	0.0504	lb
w (%)	6.22		6.02	
Average w (%)	6.12		St Dev =	0.139

Density Computations		
Mass of Mold	9.322	lb
Mass of Mold and Wet Soil	19.090	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.768	lb
Wet Density	130.2	lb/ft^3
Dry Density	122.7	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	60.6	181
0.020	153.7	459
0.030	250.8	749
0.040	323.1	965
0.050	393.4	1175
0.060	450.4	1345
0.070	519.0	1550
0.080	567.9	1696
0.090	618.1	1846
0.100	668.7	1997
0.110	714.6	2134
0.120	758.4	2265
0.130	801.6	2394
0.140	845.1	2524
0.150	890.7	2660
0.160	931.2	2781
0.170	970.4	2898
0.180	1008.9	3013
0.190	1044.0	3118
0.200	1077.9	3219
0.225	1148.2	3429
0.250	1207.4	3606
0.275	1297.2	3874
0.300	1354.8	4046
0.325	1402.0	4187
0.350	1443.5	4311
0.375	1480.7	4422
0.400	1518.2	4534
0.450	1588.8	4745
0.500	1650.1	4928



LBR 86.9

LBR Data Sheet

Description of Soil	80% RAP (3) @ woptimum = 6%	**Date**	7/2/2002 (mixed)
			7/3/2002 (compacted)
Tested By	Eric		7/5/2002 (tested)
Compaction	Modified - Method D		
Comments	Sample was tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	5		6	
Mass of Can	0.1248	lb	0.1574	lb
Mass of Wet Soil & Can	0.9742	lb	1.0002	lb
Mass of Dry Soil & Can	0.9234	lb	0.9554	lb
Mass of Dry Soil	0.7986	lb	0.798	lb
Mass of Water	0.0508	lb	0.0448	lb
w (%)	6.36		5.61	
Average w (%)	5.99		St Dev =	0.528

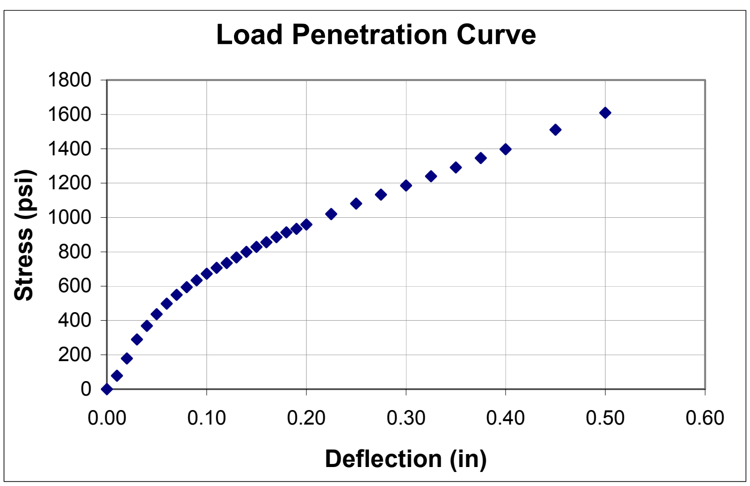
Density Computations

Mass of Mold	9.320	lb
Mass of Mold and Wet Soil	18.988	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.668	lb
Wet Density	128.9	lb/ft^3
Dry Density	121.6	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	77.3	231
0.020	178.5	533
0.030	290.0	866
0.040	369.0	1102
0.050	437.0	1305
0.060	498.6	1489
0.070	548.5	1638
0.080	594.3	1775
0.090	634.2	1894
0.100	673.0	2010
0.110	706.2	2109
0.120	734.6	2194
0.130	766.8	2290
0.140	800.3	2390
0.150	828.7	2475
0.160	855.9	2556
0.170	885.3	2644
0.180	914.1	2730
0.190	933.9	2789
0.200	958.3	2862
0.225	1019.3	3044
0.250	1080.9	3228
0.275	1133.4	3385
0.300	1186.0	3542
0.325	1239.6	3702
0.350	1290.1	3853
0.375	1346.7	4022
0.400	1396.6	4171
0.450	1510.1	4510
0.500	1609.6	4807



LBR 85

LBR Data Sheet

Description of Soil 80% RAP (4) @ woptimum = 6%

Date 7/11/2002 (mixed)
7/12/2002 (compacted)
7/14/2002 (tested)

Tested By Eric

Compaction Modified - Method D

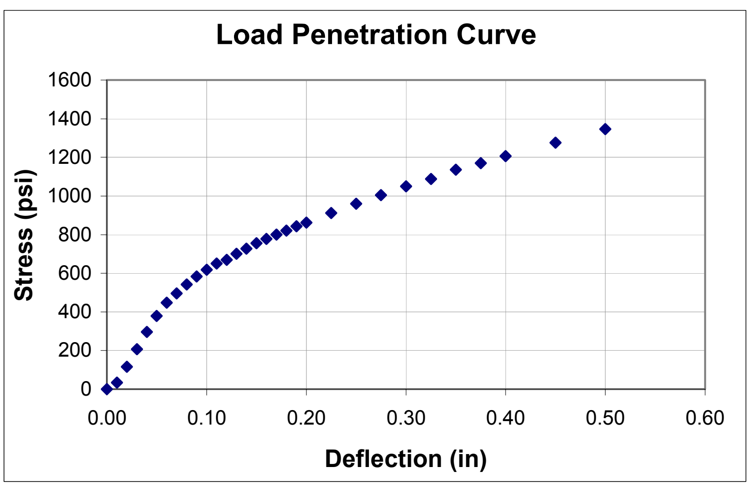
Comments Sample was tested as a base material (no surcharge)

Compaction Moisture Content				
Can Number	1		2	
Mass of Can	0.1532	lb	0.2832	lb
Mass of Wet Soil & Can	1.0028	lb	0.9270	lb
Mass of Dry Soil & Can	0.9578	lb	0.8894	lb
Mass of Dry Soil	0.8046	lb	0.6062	lb
Mass of Water	0.045	lb	0.0376	lb
w (%)	5.59		6.20	
Average w (%)	5.90		St Dev =	0.431

Density Computations		
Mass of Mold	9.320	lb
Mass of Mold and Wet Soil	18.929	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.609	lb
Wet Density	128.1	lb/ft^3
Dry Density	121.0	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	33.8	101
0.020	115.5	345
0.030	206.3	616
0.040	296.3	885
0.050	379.0	1132
0.060	447.0	1335
0.070	495.9	1481
0.080	542.4	1620
0.090	584.3	1745
0.100	617.8	1845
0.110	650.9	1944
0.120	669.7	2000
0.130	701.5	2095
0.140	727.9	2174
0.150	755.1	2255
0.160	778.5	2325
0.170	800.6	2391
0.180	820.4	2450
0.190	843.1	2518
0.200	862.2	2575
0.225	911.4	2722
0.250	959.7	2866
0.275	1004.5	3000
0.300	1049.7	3135
0.325	1088.6	3251
0.350	1136.1	3393
0.375	1169.9	3494
0.400	1206.4	3603
0.450	1275.4	3809
0.500	1346.7	4022



LBR 80

LBR Data Sheet

Description of Soil 60% RAP (1) @ woptimum = 7.8%

Date 6/24/2002 (mixed)
6/25/2002 (compacted)
6/27/2002 (tested)

Tested By Francis & Eric

Compaction Modified - Method D

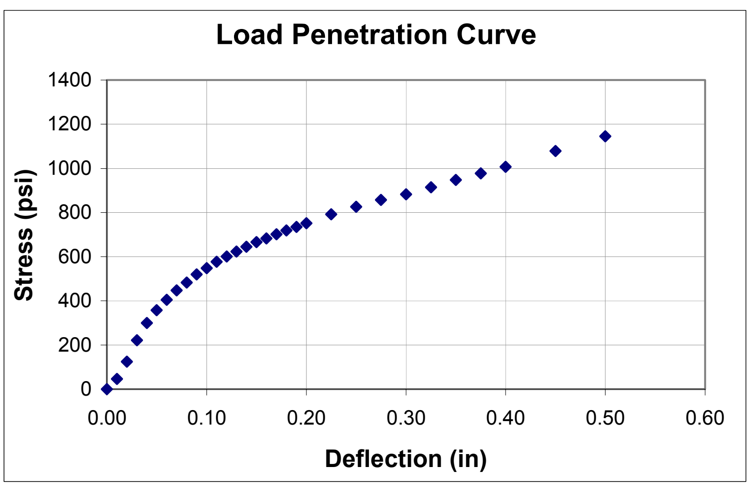
Comments Sample was tested as a base material (no surcharge)

Compaction Moisture Content				
Can Number	5		6	
Mass of Can	0.1248	lb	0.1576	lb
Mass of Wet Soil & Can	0.9890	lb	0.9808	lb
Mass of Dry Soil & Can	0.9242	lb	0.9232	lb
Mass of Dry Soil	0.7994	lb	0.7656	lb
Mass of Water	0.0648	lb	0.0576	lb
w (%)	8.11		7.52	
Average w (%)	7.81		St Dev =	0.412

Density Computations		
Mass of Mold	9.322	lb
Mass of Mold and Wet Soil	18.904	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.582	lb
Wet Density	127.7	lb/ft^3
Dry Density	118.5	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	46.9	140
0.020	124.9	373
0.030	222.0	663
0.040	300.4	897
0.050	357.3	1067
0.060	404.5	1208
0.070	447.7	1337
0.080	483.5	1444
0.090	519.7	1552
0.100	548.8	1639
0.110	576.6	1722
0.120	601.7	1797
0.130	623.1	1861
0.140	645.2	1927
0.150	666.3	1990
0.160	683.1	2040
0.170	701.8	2096
0.180	719.6	2149
0.190	735.0	2195
0.200	751.7	2245
0.225	791.6	2364
0.250	826.1	2467
0.275	856.9	2559
0.300	882.3	2635
0.325	914.5	2731
0.350	947.3	2829
0.375	977.7	2920
0.400	1007.2	3008
0.450	1079.2	3223
0.500	1145.5	3421



LBR 70

LBR Data Sheet

Description of Soil	60% RAP (2) @ woptimum = 7.8%	**Date**	7/2/2002 (mixed) 7/3/2002 (compacted) 7/5/2002 (tested)
Tested By	Eric		
Compaction	Modified - Method D		
Comments	Sample was tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	1		2	
Mass of Can	0.1532	lb	0.2832	lb
Mass of Wet Soil & Can	0.9016	lb	0.9438	lb
Mass of Dry Soil & Can	0.8458	lb	0.8956	lb
Mass of Dry Soil	0.6926	lb	0.6124	lb
Mass of Water	0.0558	lb	0.0482	lb
w (%)	8.06		7.87	
Average w (%)	7.96		St Dev =	0.131

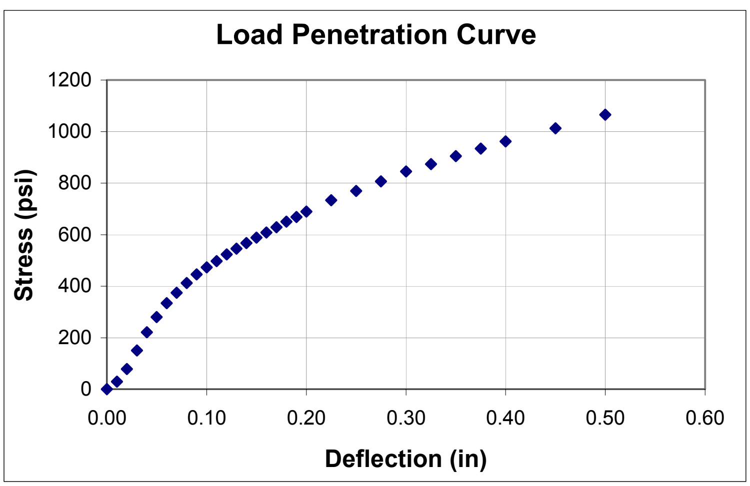
Density Computations

Mass of Mold	9.256	lb
Mass of Mold and Wet Soil	18.857	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.601	lb
Wet Density	128.0	lb/ft^3
Dry Density	118.5	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	29.5	88
0.020	78.7	235
0.030	150.3	449
0.040	221.3	661
0.050	280.3	837
0.060	334.2	998
0.070	374.7	1119
0.080	411.9	1230
0.090	445.0	1329
0.100	472.8	1412
0.110	497.2	1485
0.120	522.7	1561
0.130	545.5	1629
0.140	567.6	1695
0.150	588.0	1756
0.160	607.7	1815
0.170	628.5	1877
0.180	650.6	1943
0.190	668.3	1996
0.200	689.4	2059
0.225	733.6	2191
0.250	770.1	2300
0.275	806.6	2409
0.300	845.5	2525
0.325	873.9	2610
0.350	905.4	2704
0.375	934.2	2790
0.400	961.3	2871
0.450	1012.9	3025
0.500	1065.5	3182



LBR 61.3

LBR Data Sheet

Description of Soil 60% RAP (3) @ woptimum = 7.8%

Date 7/22/2002 (mixed)
7/23/2002 (compacted)
7/25/2002 (tested)

Tested By Eric

Compaction Modified - Method D

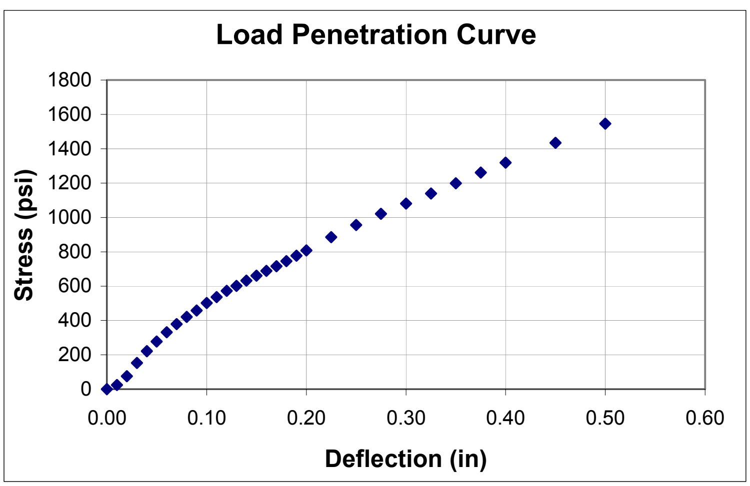
Comments Sample was tested as a base material (no surcharge)

Compaction Moisture Content				
Can Number	3		4	
Mass of Can	0.3092	lb	0.1516	lb
Mass of Wet Soil & Can	0.9444	lb	0.9990	lb
Mass of Dry Soil & Can	0.8980	lb	0.9362	lb
Mass of Dry Soil	0.5888	lb	0.7846	lb
Mass of Water	0.0464	lb	0.0628	lb
w (%)	7.88		8.00	
Average w (%)	7.94		St Dev =	0.087

Density Computations		
Mass of Mold	9.289	lb
Mass of Mold and Wet Soil	19.132	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.843	lb
Wet Density	131.2	lb/ft^3
Dry Density	121.6	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	23.8	71
0.020	74.7	223
0.030	153.7	459
0.040	220.7	659
0.050	278.6	832
0.060	332.2	992
0.070	379.0	1132
0.080	421.2	1258
0.090	458.7	1370
0.100	501.6	1498
0.110	536.4	1602
0.120	572.9	1711
0.130	601.4	1796
0.140	632.5	1889
0.150	661.0	1974
0.160	689.4	2059
0.170	716.6	2140
0.180	746.4	2229
0.190	776.8	2320
0.200	808.0	2413
0.225	885.0	2643
0.250	955.6	2854
0.275	1020.6	3048
0.300	1081.5	3230
0.325	1138.5	3400
0.350	1199.1	3581
0.375	1260.3	3764
0.400	1319.3	3940
0.450	1433.8	4282
0.500	1546.3	4618



→ **LBR 66.9**

LBR Data Sheet

Description of Soil	60% RAP (4) @ woptimum = 7.8%	**Date**	7/22/2002 (mixed) 7/23/2002 (compacted) 7/25/2002 (tested)
Tested By	Eric		
Compaction	Modified - Method D		
Comments	Sample was tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	5		6	
Mass of Can	0.1248	lb	0.1574	lb
Mass of Wet Soil & Can	0.9378	lb	0.9822	lb
Mass of Dry Soil & Can	0.8752	lb	0.9214	lb
Mass of Dry Soil	0.7504	lb	0.764	lb
Mass of Water	0.0626	lb	0.0608	lb
w (%)	8.34		7.96	
Average w (%)	8.15		St Dev =	0.272

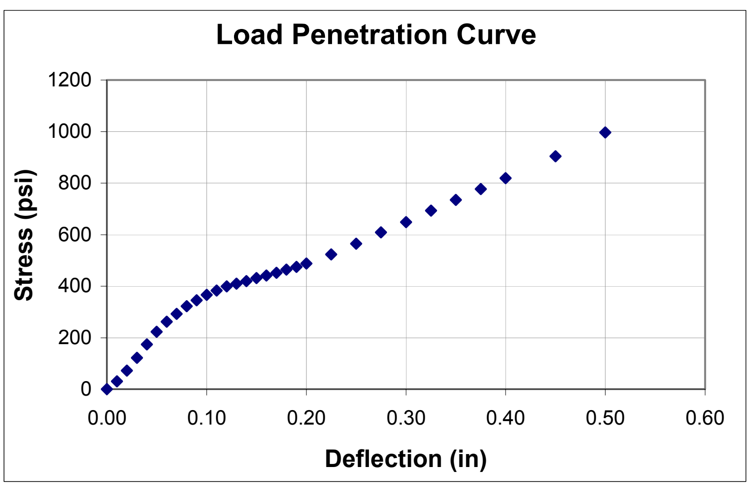
Density Computations

Mass of Mold	9.318	lb
Mass of Mold and Wet Soil	19.060	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.742	lb
Wet Density	129.9	lb/ft^3
Dry Density	120.1	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	29.8	89
0.020	71.7	214
0.030	121.9	364
0.040	174.1	520
0.050	223.0	666
0.060	261.8	782
0.070	292.3	873
0.080	322.1	962
0.090	345.2	1031
0.100	366.3	1094
0.110	383.4	1145
0.120	398.8	1191
0.130	409.8	1224
0.140	419.9	1254
0.150	430.9	1287
0.160	441.7	1319
0.170	452.0	1350
0.180	464.1	1386
0.190	475.1	1419
0.200	487.9	1457
0.225	523.0	1562
0.250	564.5	1686
0.275	609.4	1820
0.300	648.6	1937
0.325	693.1	2070
0.350	734.6	2194
0.375	777.2	2321
0.400	818.7	2445
0.450	904.1	2700
0.500	996.5	2976



LBR 46.9

LBR Data Sheet

Description of Soil	100% RAP (1) @ woptimum = 8%	**Date**	6/10/2002 (mixed)
			6/11/2002 (compacted)
Tested By	Francis & Eric		6/13/2002 (tested)
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	3		4	
Mass of Can	0.3094	lb	0.1516	lb
Mass of Wet Soil & Can	0.9562	lb	0.9678	lb
Mass of Dry Soil & Can	0.9032	lb	0.9086	lb
Mass of Dry Soil	0.5938	lb	0.757	lb
Mass of Water	0.053	lb	0.0592	lb
w (%)	8.93		7.82	
Average w (%)	8.37		St Dev =	0.782

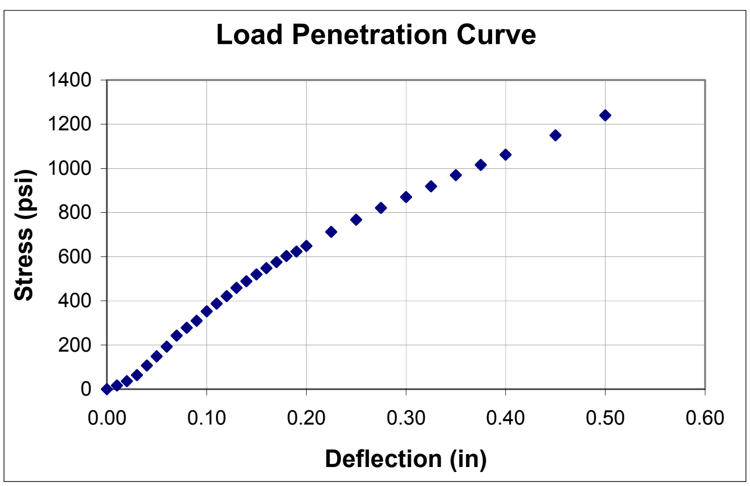
Density Computations

Mass of Mold	9.324	lb
Mass of Mold and Wet Soil	18.889	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.565	lb
Wet Density	127.5	lb/ft^3
Dry Density	117.7	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	17.1	51
0.020	36.8	110
0.030	63.6	190
0.040	106.5	318
0.050	148.7	444
0.060	193.2	577
0.070	242.8	725
0.080	277.9	830
0.090	310.4	927
0.100	352.9	1054
0.110	387.1	1156
0.120	421.2	1258
0.130	458.4	1369
0.140	488.2	1458
0.150	520.0	1553
0.160	547.8	1636
0.170	576.3	1721
0.180	603.7	1803
0.190	623.8	1863
0.200	648.3	1936
0.225	712.5	2128
0.250	767.8	2293
0.275	820.4	2450
0.300	870.3	2599
0.325	919.1	2745
0.350	969.4	2895
0.375	1015.9	3034
0.400	1062.5	3173
0.450	1149.5	3433
0.500	1239.6	3702



LBR 50.6

LBR Data Sheet

Description of Soil	100% RAP (2) @ woptimum = 8%
Tested By	Francis
Compaction	Modified - Method D
Comments	Tested as a subgrade material (15 lb surcharge)

Date

6/14/2002	(mixed)
6/15/2002	(compacted)
6/17/2002	(tested)

Compaction Moisture Content

Can Number	1		2	
Mass of Can	0.1534	lb	0.2834	lb
Mass of Wet Soil & Can	0.8226	lb	1.0184	lb
Mass of Dry Soil & Can	0.7718	lb	0.9666	lb
Mass of Dry Soil	0.6184	lb	0.6832	lb
Mass of Water	0.0508	lb	0.0518	lb
w (%)	8.21		7.58	
Average w (%)	7.90		St Dev =	0.447

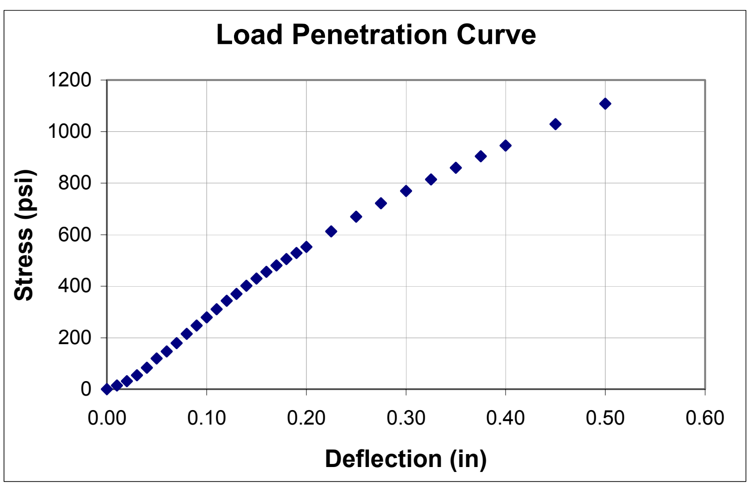
Density Computations

Mass of Mold	9.2585	lb
Mass of Mold and Wet Soil	18.811	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.5525	lb
Wet Density	127.3	lb/ft^3
Dry Density	118.0	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	14.4	43
0.020	31.1	93
0.030	54.2	162
0.040	83.0	248
0.050	119.5	357
0.060	146.3	437
0.070	179.1	535
0.080	214.3	640
0.090	246.4	736
0.100	278.9	833
0.110	310.1	926
0.120	342.9	1024
0.130	370.0	1105
0.140	401.8	1200
0.150	429.3	1282
0.160	455.4	1360
0.170	480.5	1435
0.180	505.3	1509
0.190	529.1	1580
0.200	551.8	1648
0.225	612.8	1830
0.250	669.7	2000
0.275	721.3	2154
0.300	770.1	2300
0.325	814.3	2432
0.350	859.9	2568
0.375	903.7	2699
0.400	945.6	2824
0.450	1028.6	3072
0.500	1108.7	3311



LBR 40

LBR Data Sheet

Description of Soil 100% RAP (3) @ woptimum = 8%

Date 6/14/2002 (mixed)
6/15/2002 (compacted)
6/17/2002 (tested)

Tested By Francis

Compaction Modified - Method D

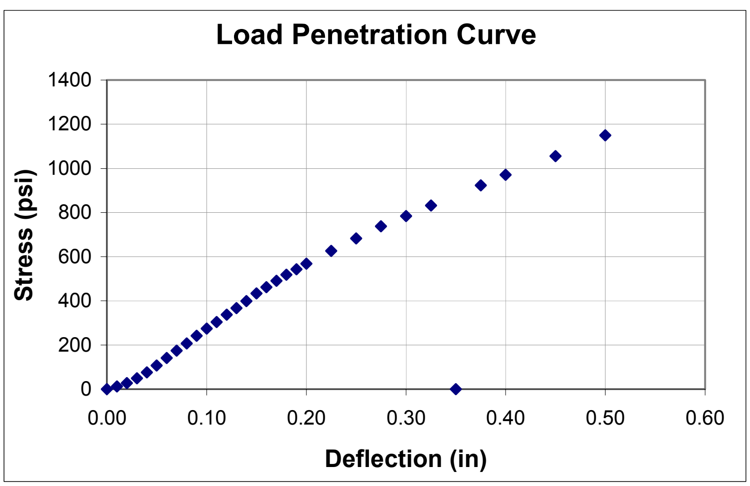
Comments Tested as a subgrade material (15 lb surcharge)

Compaction Moisture Content				
Can Number	3		4	
Mass of Can	0.3092	lb	0.1516	lb
Mass of Wet Soil & Can	0.9456	lb	1.0282	lb
Mass of Dry Soil & Can	0.8984	lb	0.9652	lb
Mass of Dry Soil	0.5892	lb	0.8136	lb
Mass of Water	0.0472	lb	0.063	lb
w (%)	8.01		7.74	
Average w (%)	7.88		St Dev =	0.189

Density Computations		
Mass of Mold	9.295	lb
Mass of Mold and Wet Soil	18.793	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.498	lb
Wet Density	126.6	lb/ft^3
Dry Density	117.4	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	11.7	35
0.020	27.1	81
0.030	49.9	149
0.040	76.0	227
0.050	107.5	321
0.060	141.0	421
0.070	173.8	519
0.080	207.9	621
0.090	241.1	720
0.100	274.6	820
0.110	304.0	908
0.120	337.2	1007
0.130	367.7	1098
0.140	399.1	1192
0.150	433.3	1294
0.160	462.1	1380
0.170	490.9	1466
0.180	518.0	1547
0.190	543.1	1622
0.200	568.6	1698
0.225	626.8	1872
0.250	683.1	2040
0.275	738.0	2204
0.300	784.5	2343
0.325	831.7	2484
0.350	#VALUE!	-
0.375	923.5	2758
0.400	970.7	2899
0.450	1056.1	3154
0.500	1149.5	3433



→ **LBR 41**

LBR Data Sheet

Description of Soil	100% RAP (4) @ woptimum = 8%	**Date**	6/18/2002 (mixed) 6/19/2002 (compacted) 6/21/2002 (tested)
Tested By	Francis		
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	1		2	
Mass of Can	0.1534	lb	0.2834	lb
Mass of Wet Soil & Can	0.9966	lb	1.0568	lb
Mass of Dry Soil & Can	0.9356	lb	1.0040	lb
Mass of Dry Soil	0.7822	lb	0.7206	lb
Mass of Water	0.061	lb	0.0528	lb
w (%)	7.80		7.33	
Average w (%)	7.56		St Dev =	0.333

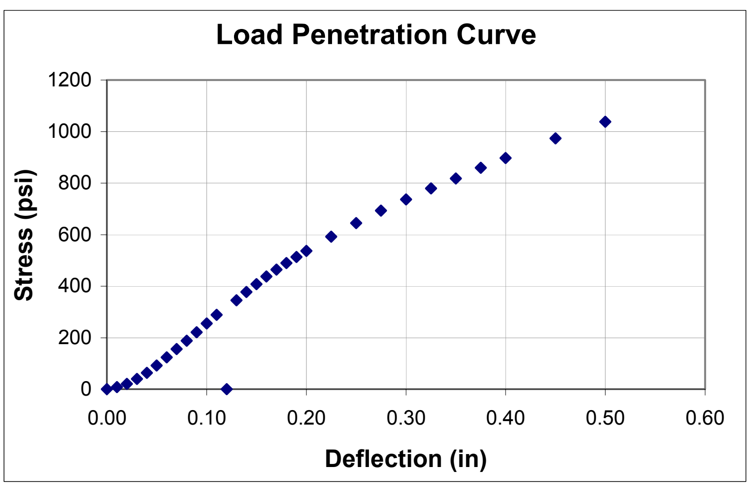
Density Computations

Mass of Mold	9.257	lb
Mass of Mold and Wet Soil	18.738	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.481	lb
Wet Density	126.4	lb/ft^3
Dry Density	117.5	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	8.4	25
0.020	20.4	61
0.030	39.8	119
0.040	63.6	190
0.050	92.1	275
0.060	123.6	369
0.070	156.4	467
0.080	188.5	563
0.090	221.7	662
0.100	255.2	762
0.110	288.0	860
0.120	#VALUE!	-
0.130	345.2	1031
0.140	377.4	1127
0.150	407.2	1216
0.160	437.6	1307
0.170	464.8	1388
0.180	490.2	1464
0.190	513.6	1534
0.200	537.4	1605
0.225	591.7	1767
0.250	645.2	1927
0.275	693.5	2071
0.300	736.3	2199
0.325	778.8	2326
0.350	818.0	2443
0.375	859.2	2566
0.400	897.4	2680
0.450	974.4	2910
0.500	1038.0	3100



LBR 39.9

LBR Data Sheet

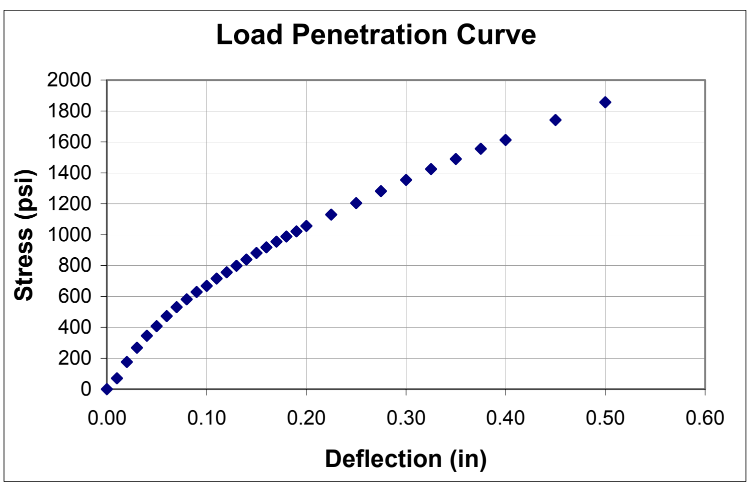
Description of Soil	80% RAP (1) @ woptimum = 6%	**Date**	6/10/2002 (mixed)
			6/11/2002 (compacted)
Tested By	Francis & Eric		6/13/2002 (tested)
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content				
Can Number	7		8	
Mass of Can	0.2790	lb	0.1326	lb
Mass of Wet Soil & Can	1.0378	lb	0.9466	lb
Mass of Dry Soil & Can	0.9984	lb	0.9016	lb
Mass of Dry Soil	0.7194	lb	0.769	lb
Mass of Water	0.0394	lb	0.045	lb
w (%)	5.48		5.85	
Average w (%)	5.66		St Dev =	0.265

Density Computations		
Mass of Mold	9.295	lb
Mass of Mold and Wet Soil	19.037	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.742	lb
Wet Density	129.9	lb/ft^3
Dry Density	122.9	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	70.3	210
0.020	176.5	527
0.030	267.5	799
0.040	345.2	1031
0.050	408.5	1220
0.060	473.5	1414
0.070	530.4	1584
0.080	581.6	1737
0.090	629.2	1879
0.100	669.0	1998
0.110	715.2	2136
0.120	757.1	2261
0.130	798.6	2385
0.140	838.8	2505
0.150	880.3	2629
0.160	916.8	2738
0.170	955.0	2852
0.180	988.8	2953
0.190	1021.9	3052
0.200	1055.8	3153
0.225	1130.8	3377
0.250	1203.4	3594
0.275	1280.8	3825
0.300	1354.4	4045
0.325	1424.4	4254
0.350	1490.1	4450
0.375	1555.7	4646
0.400	1612.6	4816
0.450	1742.2	5203
0.500	1857.0	5546



LBR 86.3

LBR Data Sheet

Description of Soil	80% RAP (2) @ woptimum = 6%	**Date**	6/14/2002 (mixed) 6/15/2002 (compacted) 6/17/2002 (tested)
Tested By	Francis		
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	5		6	
Mass of Can	0.1248	lb	0.1574	lb
Mass of Wet Soil & Can	0.9700	lb	0.9372	lb
Mass of Dry Soil & Can	0.9196	lb	0.8948	lb
Mass of Dry Soil	0.7948	lb	0.7374	lb
Mass of Water	0.0504	lb	0.0424	lb
w (%)	6.34		5.75	
Average w (%)	6.05		St Dev =	0.418

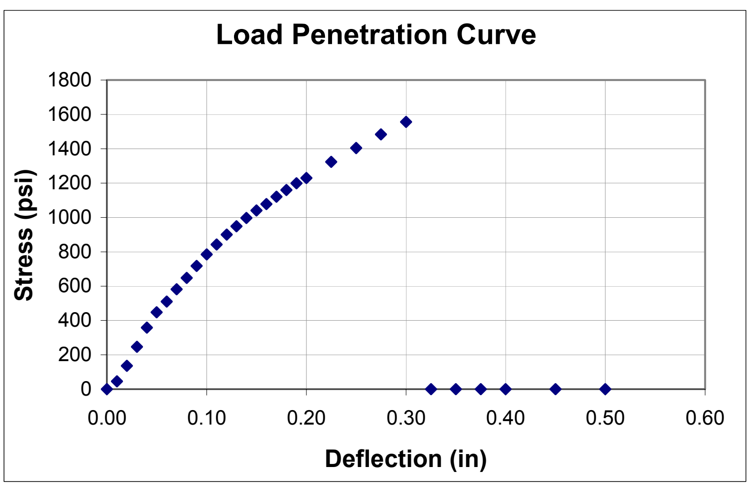
Density Computations

Mass of Mold	9.323	lb
Mass of Mold and Wet Soil	19.153	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.83	lb
Wet Density	131.0	lb/ft^3
Dry Density	123.6	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	45.9	137
0.020	135.9	406
0.030	246.4	736
0.040	358.3	1070
0.050	448.7	1340
0.060	510.3	1524
0.070	581.6	1737
0.080	648.9	1938
0.090	717.9	2144
0.100	784.5	2343
0.110	842.8	2517
0.120	901.4	2692
0.130	949.6	2836
0.140	996.5	2976
0.150	1041.0	3109
0.160	1078.5	3221
0.170	1120.7	3347
0.180	1159.9	3464
0.190	1198.4	3579
0.200	1229.9	3673
0.225	1323.6	3953
0.250	1404.3	4194
0.275	1483.7	4431
0.300	1556.7	4649
0.325	#VALUE!	-
0.350	#VALUE!	-
0.375	#VALUE!	-
0.400	#VALUE!	-
0.450	#VALUE!	-
0.500	#VALUE!	-



LBR 102.5

LBR Data Sheet

Description of Soil	80% RAP (3) @ woptimum = 6%	**Date**	7/11/2002 (mixed)
			7/12/2002 (compacted)
Tested By	Eric		7/14/2002 (tested)
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	5		6	
Mass of Can	0.1248	lb	0.1574	lb
Mass of Wet Soil & Can	0.9364	lb	0.9350	lb
Mass of Dry Soil & Can	0.8816	lb	0.8822	lb
Mass of Dry Soil	0.7568	lb	0.7248	lb
Mass of Water	0.0548	lb	0.0528	lb
w (%)	7.24		7.28	
Average w (%)	7.26		St Dev =	0.031

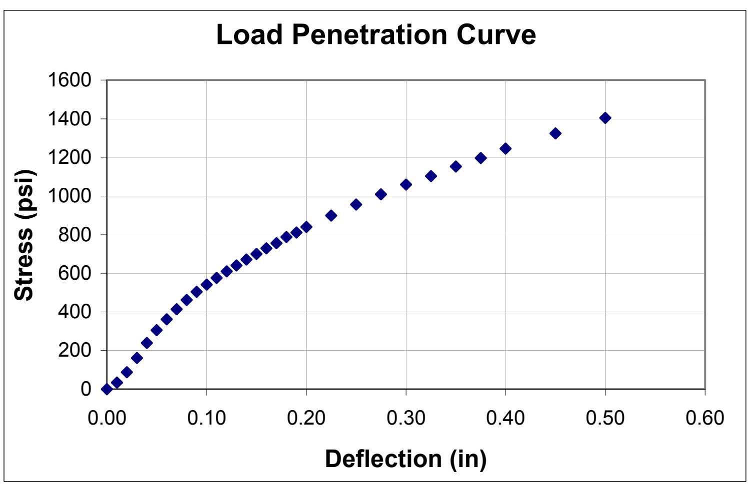
Density Computations

Mass of Mold	9.291	lb
Mass of Mold and Wet Soil	18.924	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.633	lb
Wet Density	128.4	lb/ft^3
Dry Density	119.7	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	34.5	103
0.020	88.1	263
0.030	161.4	482
0.040	240.1	717
0.050	304.7	910
0.060	362.0	1081
0.070	413.9	1236
0.080	461.1	1377
0.090	504.3	1506
0.100	540.8	1615
0.110	576.3	1721
0.120	610.1	1822
0.130	639.9	1911
0.140	670.4	2002
0.150	699.8	2090
0.160	728.3	2175
0.170	755.7	2257
0.180	787.9	2353
0.190	811.3	2423
0.200	839.5	2507
0.225	899.4	2686
0.250	956.3	2856
0.275	1008.5	3012
0.300	1059.4	3164
0.325	1102.6	3293
0.350	1152.9	3443
0.375	1197.1	3575
0.400	1245.9	3721
0.450	1324.0	3954
0.500	1404.0	4193



LBR 80.3

LBR Data Sheet

Description of Soil 80% RAP (4) @ woptimum = 6%

Date 7/11/2002 (mixed)
7/12/2002 (compacted)
7/14/2002 (tested)

Tested By Eric

Compaction Modified - Method D

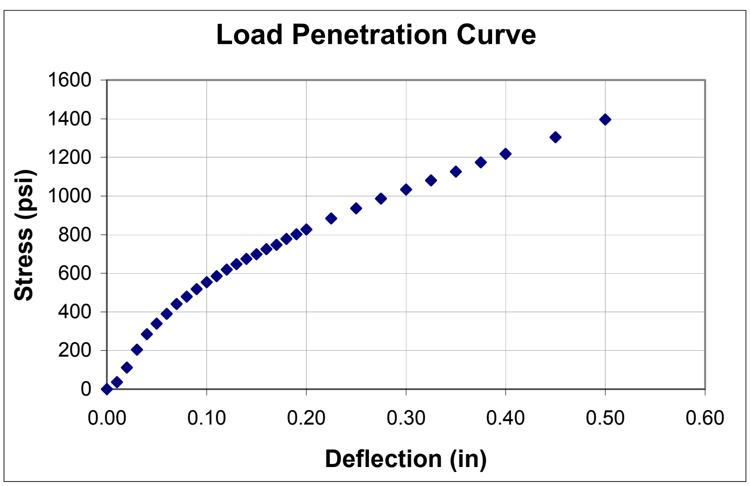
Comments Tested as a subgrade material (15 lb surcharge)

Compaction Moisture Content				
Can Number	3		4	
Mass of Can	0.3092	lb	0.1514	lb
Mass of Wet Soil & Can	0.9322	lb	0.9322	lb
Mass of Dry Soil & Can	0.8936	lb	0.8858	lb
Mass of Dry Soil	0.5844	lb	0.7344	lb
Mass of Water	0.0386	lb	0.0464	lb
w (%)	6.61		6.32	
Average w (%)	6.46		St Dev =	0.203

Density Computations		
Mass of Mold	9.255	lb
Mass of Mold and Wet Soil	18.878	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.623	lb
Wet Density	128.3	lb/ft^3
Dry Density	120.5	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	36.2	108
0.020	112.2	335
0.030	204.6	611
0.040	284.6	850
0.050	339.2	1013
0.060	389.8	1164
0.070	441.7	1319
0.080	479.5	1432
0.090	518.0	1547
0.100	553.2	1652
0.110	585.6	1749
0.120	619.1	1849
0.130	646.2	1930
0.140	674.4	2014
0.150	698.8	2087
0.160	724.9	2165
0.170	748.0	2234
0.180	778.5	2325
0.190	801.6	2394
0.200	827.4	2471
0.225	883.3	2638
0.250	935.2	2793
0.275	986.1	2945
0.300	1034.3	3089
0.325	1080.9	3228
0.350	1126.4	3364
0.375	1174.0	3506
0.400	1217.8	3637
0.450	1303.5	3893
0.500	1396.3	4170



LBR 72.5

LBR Data Sheet

Description of Soil	60% RAP (1) @ woptimum = 7.8%	**Date**	6/24/2002 (mixed) 6/25/2002 (compacted) 6/27/2002 (tested)
Tested By	Francis & Eric		
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	1		2	
Mass of Can	0.1534	lb	0.2836	lb
Mass of Wet Soil & Can	0.9378	lb	0.9214	lb
Mass of Dry Soil & Can	0.8812	lb	0.8788	lb
Mass of Dry Soil	0.7278	lb	0.5952	lb
Mass of Water	0.0566	lb	0.0426	lb
w (%)	7.78		7.16	
Average w (%)	7.47		St Dev =	0.438

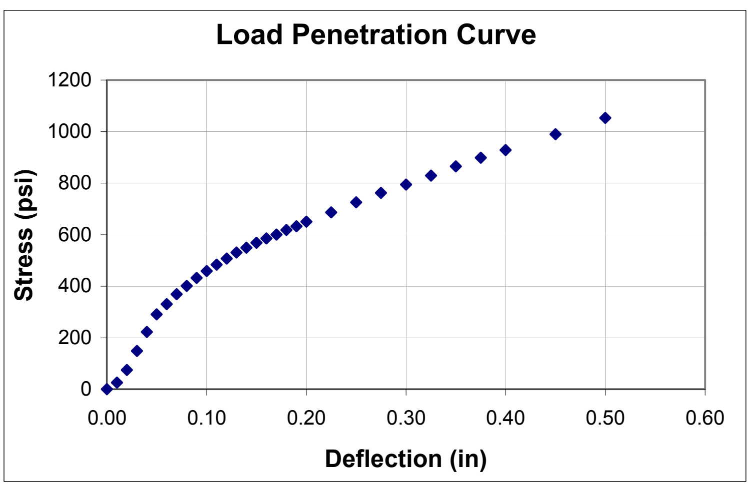
Density Computations

Mass of Mold	9.256	lb
Mass of Mold and Wet Soil	18.800	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.544	lb
Wet Density	127.2	lb/ft^3
Dry Density	118.4	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	25.4	76
0.020	75.0	224
0.030	148.7	444
0.040	222.0	663
0.050	290.0	866
0.060	330.5	987
0.070	369.0	1102
0.080	401.1	1198
0.090	432.6	1292
0.100	459.1	1371
0.110	483.5	1444
0.120	507.0	1514
0.130	530.1	1583
0.140	549.5	1641
0.150	567.9	1696
0.160	585.0	1747
0.170	600.0	1792
0.180	618.1	1846
0.190	632.2	1888
0.200	650.3	1942
0.225	686.4	2050
0.250	725.6	2167
0.275	762.1	2276
0.300	794.2	2372
0.325	829.4	2477
0.350	865.2	2584
0.375	898.4	2683
0.400	928.9	2774
0.450	989.8	2956
0.500	1053.1	3145



→ **LBR 60**

LBR Data Sheet

Description of Soil	60% RAP (2) @ woptimum = 7.8%	**Date**	6/24/2002 (mixed)
			6/25/2002 (compacted)
Tested By	Francis & Eric		6/27/2002 (tested)
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	3		4	
Mass of Can	0.3094	lb	0.1516	lb
Mass of Wet Soil & Can	0.9792	lb	0.9372	lb
Mass of Dry Soil & Can	0.9286	lb	0.8780	lb
Mass of Dry Soil	0.6192	lb	0.7264	lb
Mass of Water	0.0506	lb	0.0592	lb
w (%)	8.17		8.15	
Average w (%)	8.16		St Dev =	0.016

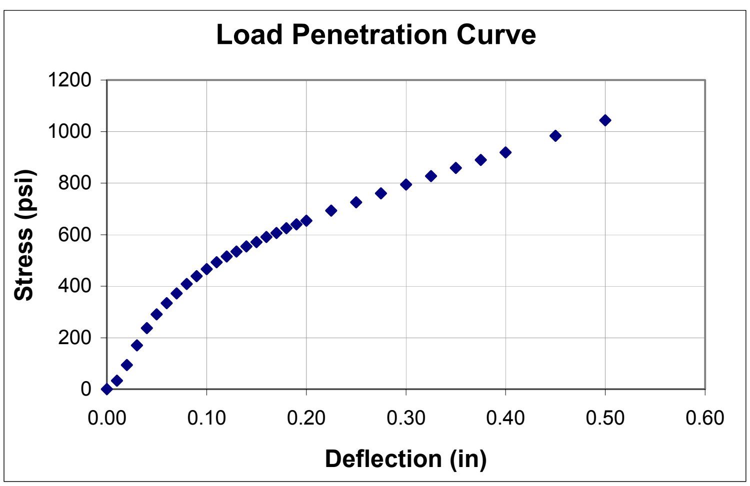
Density Computations

Mass of Mold	9.293	lb
Mass of Mold and Wet Soil	18.838	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.545	lb
Wet Density	127.2	lb/ft^3
Dry Density	117.6	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	33.5	100
0.020	93.8	280
0.030	170.1	508
0.040	237.1	708
0.050	290.0	866
0.060	333.5	996
0.070	371.7	1110
0.080	408.8	1221
0.090	438.6	1310
0.100	465.8	1391
0.110	492.9	1472
0.120	515.3	1539
0.130	534.4	1596
0.140	553.8	1654
0.150	571.6	1707
0.160	591.0	1765
0.170	606.4	1811
0.180	624.8	1866
0.190	639.9	1911
0.200	654.3	1954
0.225	693.5	2071
0.250	725.6	2167
0.275	760.1	2270
0.300	793.9	2371
0.325	827.7	2472
0.350	858.5	2564
0.375	889.7	2657
0.400	919.5	2746
0.450	983.8	2938
0.500	1044.0	3118



→ **LBR 61.3**

LBR Data Sheet

Description of Soil	60% RAP (3) @ woptimum = 7.8%	**Date**	7/2/2002 (mixed)
			7/3/2003 (compacted)
Tested By	Eric		7/5/2002 (tested)
Compaction	Modified - Method D		
Comments	Tested as a subgrade material (15 lb surcharge)		

Compaction Moisture Content

Can Number	3		4	
Mass of Can	0.3092	lb	0.1516	lb
Mass of Wet Soil & Can	0.9786	lb	0.9882	lb
Mass of Dry Soil & Can	0.9300	lb	0.9248	lb
Mass of Dry Soil	0.6208	lb	0.7732	lb
Mass of Water	0.0486	lb	0.0634	lb
w (%)	7.83		8.20	
Average w (%)	8.01		St Dev =	0.262

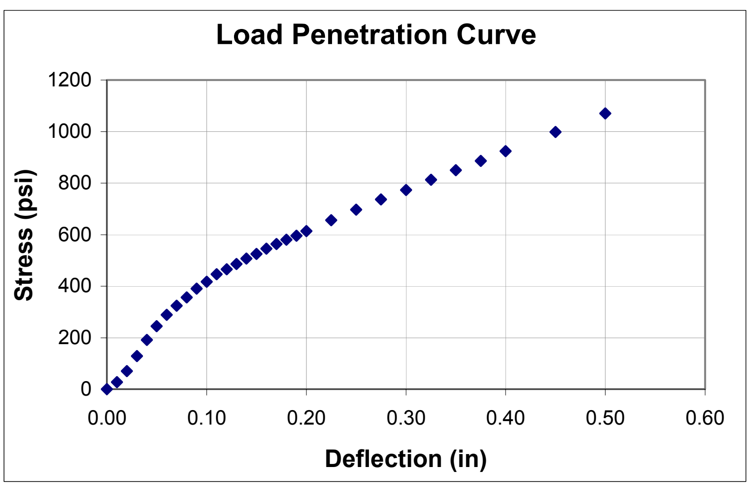
Density Computations

Mass of Mold	9.291	lb
Mass of Mold and Wet Soil	18.886	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.595	lb
Wet Density	127.9	lb/ft^3
Dry Density	118.4	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	27.1	81
0.020	70.0	209
0.030	128.2	383
0.040	191.2	571
0.050	245.1	732
0.060	288.0	860
0.070	324.8	970
0.080	356.6	1065
0.090	390.1	1165
0.100	417.2	1246
0.110	446.0	1332
0.120	465.4	1390
0.130	485.9	1451
0.140	507.0	1514
0.150	525.0	1568
0.160	545.8	1630
0.170	563.2	1682
0.180	580.6	1734
0.190	596.0	1780
0.200	613.8	1833
0.225	656.0	1959
0.250	696.8	2081
0.275	736.3	2199
0.300	773.8	2311
0.325	813.7	2430
0.350	849.8	2538
0.375	886.3	2647
0.400	924.2	2760
0.450	998.8	2983
0.500	1070.2	3196



LBR 55.0

LBR Data Sheet

Description of Soil 60% RAP (4) @ woptimum = 7.8%

Date 7/22/2002 (mixed)
7/23/2002 (compacted)
7/25/2002 (tested)

Tested By Eric

Compaction Modified - Method D

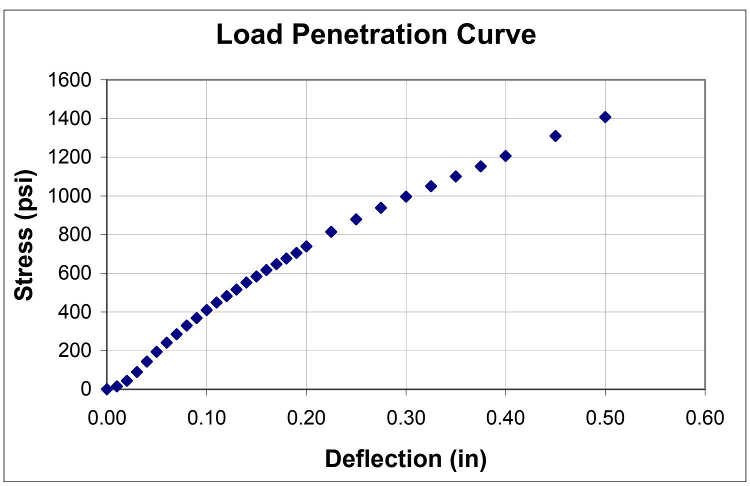
Comments Tested as a subgrade material (15 lb surcharge)

Compaction Moisture Content				
Can Number	1		2	
Mass of Can	0.1532	lb	0.2832	lb
Mass of Wet Soil & Can	0.9646	lb	0.9880	lb
Mass of Dry Soil & Can	0.9020	lb	0.9364	lb
Mass of Dry Soil	0.7488	lb	0.6532	lb
Mass of Water	0.0626	lb	0.0516	lb
w (%)	8.36		7.90	
Average w (%)	8.13		St Dev =	0.326

Density Computations		
Mass of Mold	9.254	lb
Mass of Mold and Wet Soil	19.160	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.906	lb
Wet Density	132.0	lb/ft^3
Dry Density	122.1	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	15.4	46
0.020	44.2	132
0.030	89.1	266
0.040	143.6	429
0.050	193.5	578
0.060	241.1	720
0.070	285.3	852
0.080	329.5	984
0.090	368.3	1100
0.100	409.5	1223
0.110	448.4	1339
0.120	482.2	1440
0.130	515.3	1539
0.140	552.8	1651
0.150	584.0	1744
0.160	617.1	1843
0.170	647.3	1933
0.180	676.0	2019
0.190	705.2	2106
0.200	739.0	2207
0.225	814.0	2431
0.250	878.6	2624
0.275	938.6	2803
0.300	996.2	2975
0.325	1049.7	3135
0.350	1101.3	3289
0.375	1152.9	3443
0.400	1206.4	3603
0.450	1310.2	3913
0.500	1407.7	4204



LBR 57.5

LBR Data Sheet

Description of Soil	100% RAP (1) @ woptimum = 8%	**Date**	2/3/2003 (mixed)
Tested By	Eric		2/4/2003 (compacted)
Compaction	Double Modified		2/6/2003 (tested)
Comments	Tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	9		10	
Mass of Can	0.0970	lb	0.1490	lb
Mass of Wet Soil & Can	0.5800	lb	0.6140	lb
Mass of Dry Soil & Can	0.5430	lb	0.5810	lb
Mass of Dry Soil	0.446	lb	0.432	lb
Mass of Water	0.037	lb	0.033	lb
w (%)	8.30		7.64	
Average w (%)	7.97		St Dev =	0.465

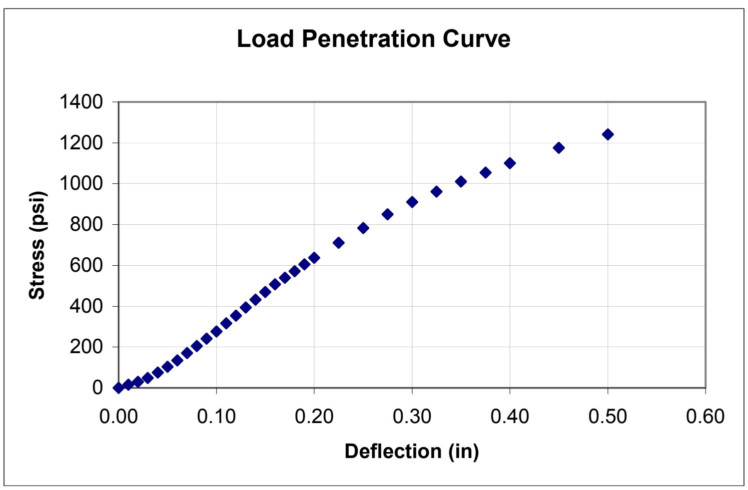
Density Computations

Mass of Mold	9.284	lb
Mass of Mold and Wet Soil	18.985	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.701	lb
Wet Density	129.3	lb/ft^3
Dry Density	119.8	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	15.1	45
0.020	29.5	88
0.030	49.2	147
0.040	75.3	225
0.050	103.5	309
0.060	134.3	401
0.070	170.1	508
0.080	204.6	611
0.090	241.4	721
0.100	276.2	825
0.110	316.1	944
0.120	353.9	1057
0.130	394.1	1177
0.140	432.3	1291
0.150	469.4	1402
0.160	506.3	1512
0.170	538.4	1608
0.180	571.2	1706
0.190	604.4	1805
0.200	636.2	1900
0.225	710.9	2123
0.250	782.9	2338
0.275	850.5	2540
0.300	910.1	2718
0.325	961.7	2872
0.350	1010.6	3018
0.375	1054.8	3150
0.400	1100.3	3286
0.450	1175.6	3511
0.500	1241.6	3708



LBR 46.3

LBR Data Sheet

Description of Soil	100% RAP (2) @ woptimum = 8%	**Date**	3/3/2003 (mixed)
			3/4/2003 (compacted)
Tested By	Eric		3/6/2003 (tested)
Compaction	Double Modified		
Comments	Tested as a base material (no surcharge)		

Compaction Moisture Content

Can Number	8		5	
Mass of Can	0.1330	lb	0.1240	lb
Mass of Wet Soil & Can	1.1900	lb	1.0020	lb
Mass of Dry Soil & Can	1.1130	lb	0.9380	lb
Mass of Dry Soil	0.98	lb	0.814	lb
Mass of Water	0.077	lb	0.064	lb
w (%)	7.86		7.86	
Average w (%)	7.86		St Dev =	0.004

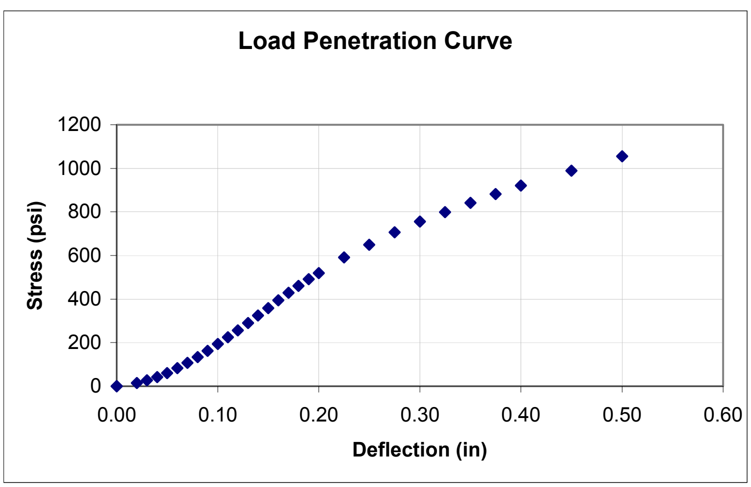
Density Computations

Mass of Mold	9.252	lb
Mass of Mold and Wet Soil	18.954	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.702	lb
Wet Density	129.3	lb/ft^3
Dry Density	119.9	lb/ft^3

Measurements

Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.000	0.0	
0.020	14.4	43
0.030	26.5	79
0.040	41.5	124
0.050	60.3	180
0.060	82.4	246
0.070	107.1	320
0.080	133.3	398
0.090	162.1	484
0.100	193.9	579
0.110	225.0	672
0.120	256.5	766
0.130	290.3	867
0.140	324.8	970
0.150	357.9	1069
0.160	394.4	1178
0.170	428.3	1279
0.180	460.4	1375
0.190	491.5	1468
0.200	519.7	1552
0.225	591.3	1766
0.250	648.9	1938
0.275	706.5	2110
0.300	755.1	2255
0.325	798.9	2386
0.350	842.1	2515
0.375	882.6	2636
0.400	920.8	2750
0.450	989.5	2955
0.500	1056.1	3154



LBR 40.9

LBR Data Sheet

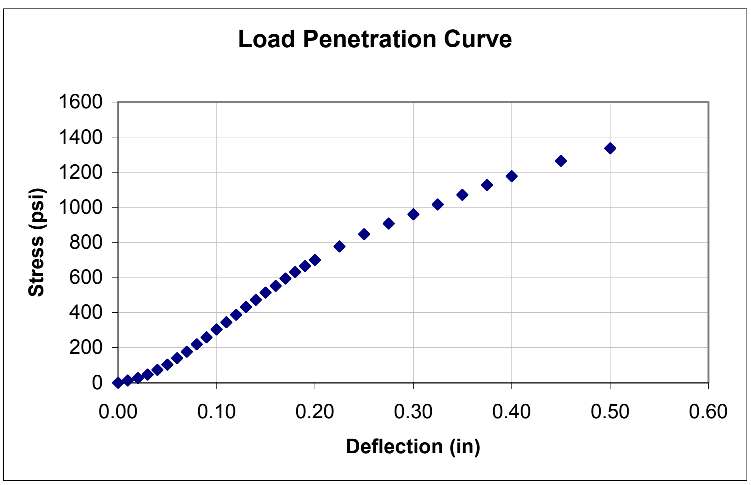
Description of Soil	100% RAP (3) @ woptimum = 8%	**Date**	3/3/2003 (mixed)
Tested By	Eric		3/4/2003 (compacted)
Compaction	Double Modified		3/6/2003 (tested)
Comments	Tested as a base material (no surcharge)		

Compaction Moisture Content				
Can Number	9		10	
Mass of Can	0.0980	lb	0.1470	lb
Mass of Wet Soil & Can	1.1570	lb	0.8630	lb
Mass of Dry Soil & Can	1.0760	lb	0.8090	lb
Mass of Dry Soil	0.978	lb	0.662	lb
Mass of Water	0.081	lb	0.054	lb
w (%)	8.28		8.16	
Average w (%)	8.22		St Dev =	0.088

Density Computations		
Mass of Mold	9.316	lb
Mass of Mold and Wet Soil	19.093	lb
Vol of Mold	0.07502	ft^3
Mass of Wet Soil	9.777	lb
Wet Density	130.3	lb/ft^3
Dry Density	120.4	lb/ft^3

Measurements		
Diameter of Piston	1.95	in
Area of Piston	2.98648	in^2

Deflection (in)	Stress (psi)	Load (lb)
0.000	0.0	0
0.010	12.7	38
0.020	26.8	80
0.030	46.5	139
0.040	72.7	217
0.050	103.5	309
0.060	139.0	415
0.070	177.1	529
0.080	218.3	652
0.090	259.2	774
0.100	302.4	903
0.110	345.2	1031
0.120	387.4	1157
0.130	430.6	1286
0.140	472.8	1412
0.150	513.3	1533
0.160	551.5	1647
0.170	593.3	1772
0.180	631.2	1885
0.190	665.0	1986
0.200	699.2	2088
0.225	776.8	2320
0.250	846.1	2527
0.275	907.4	2710
0.300	960.7	2869
0.325	1015.6	3033
0.350	1070.2	3196
0.375	1125.4	3361
0.400	1178.0	3518
0.450	1264.7	3777
0.500	1335.4	3988



LBR 53.0

Appendix I

RAP-Soil Mixtures Mohr-Coulomb Failure Envelopes

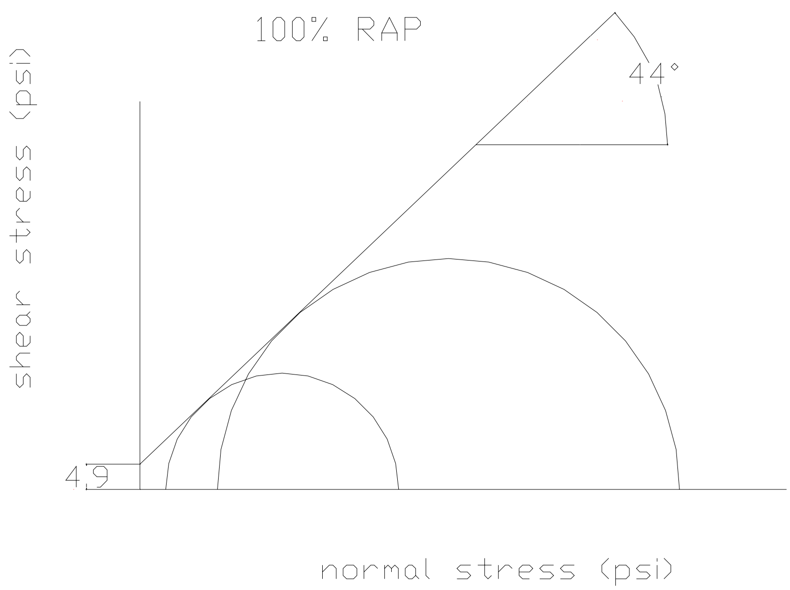


Figure I-1. Mohr-Coulomb failure envelope of 100% RAP

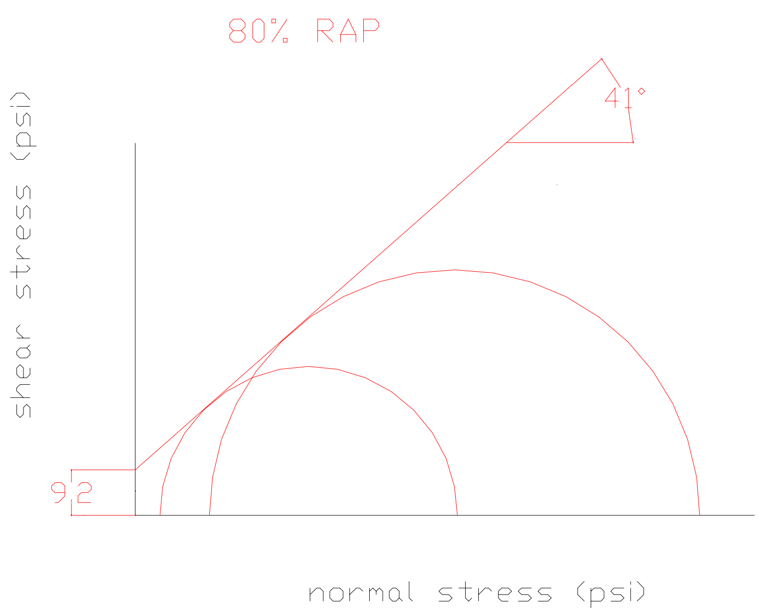


Figure I-2. Mohr-Coulomb failure envelope of 80% RAP

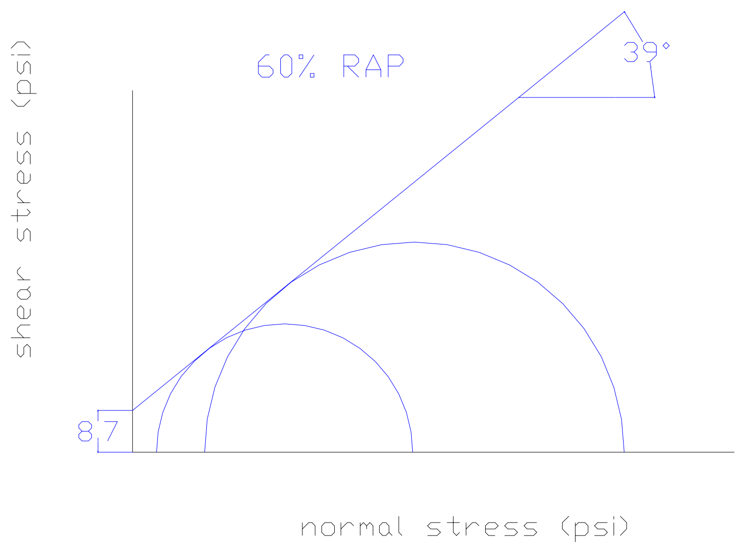


Figure I-3. Mohr-Coulomb failure envelope of 60% RAP

Appendix J

Surface and Leachate Water Data

Table J.1 Silver (Ag) concentration versus time in surface runoff and leachate samples collected from the RAP and Limerock collection systems.

Time of Exposure (days)	Concentrations (μg/l) [b]					
	RAP Surface Runoff 1 [a]	RAP Surface Runoff 2 [a]	RAP Leachate	Limerock Surface Runoff 1 [a]	Limerock Surface Runoff 2 [a]	Limerock Leachate
38	BDL	-	-	-	-	-
44	1.25	-	BDL	BDL	-	1.01
58	2.31	-	2.09	-	-	1.98
61	1.95	-	2.02	-	-	2.38
80	1.59	-	1.45	1.63	-	1.56
90	1.94	-	1.71	1.87	-	1.43
99	1.72	-	1.49	-	1.68	1.32
110	-	-	-	1.08	-	-
122	BDL	-	BDL	-	-	BDL
134	BDL	BDL	1.15	1.27	1.28	1.09
141	-	-	-	BDL	-	-
147	BDL	BDL	BDL	BDL	-	BDL
155	BDL	BDL	BDL	BDL	1.04	BDL
165	BDL	BDL	BDL	-	BDL	BDL

"-" = Insufficient quantity for collection
BDL = below detection limit, Ag < 1 μg/l
[a] Samples were collected from separate collection tanks
[b] EPA Standard = 1000 μg/l

Table J.2 Cadmium (Cd) concentration versus Time in surface runoff and leachate samples collected from the RAP and Limerock collection systems.

Time of Exposure (days)	Concentrations (μg/l) [b]					
	RAP Surface Runoff 1 [a]	RAP Surface Runoff 2 [a]	RAP Leachate	Limerock Surface Runoff 1 [a]	Limerock Surface Runoff 2 [a]	Limerock Leachate
38	2.78	-	-	-	-	-
44	BDL	-	BDL	2.21	-	BDL
58	BDL	-	BDL	-	-	BDL
61	BDL	-	BDL	-	-	BDL
80	BDL	-	BDL	BDL	-	BDL
90	BDL	-	BDL	BDL	-	BDL
99	BDL	-	BDL	-	BDL	BDL
110	-	-	-	BDL	-	-
122	BDL	-	BDL	-	-	BDL
134	BDL	BDL	BDL	BDL	BDL	BDL
141	-	-	-	3.28	-	-
147	BDL	BDL	BDL	BDL	-	BDL
155	BDL	BDL	BDL	BDL	BDL	BDL
165	BDL	BDL	BDL	-	BDL	BDL

"-" = Insufficient quantity for analysis
BDL = Below detection limit, Cd < 1 μg/l
[a] Samples were colleted from separate collection tanks
[b] EPA Standard = 1000 μg/l

Table J.3 Chromium (Cr) concentration versus Time in surface runoff and leachate collected from the RAP and Limerock collection systems.

Time of Exposure (days)	Concentrations (μg/l) [b]					
	RAP Surface Runoff 1 [a]	RAP Surface Runoff 2 [a]	RAP Leachate	Limerock Surface Runoff 1 [a]	Limerock Surface Runoff 2 [a]	Limerock Leachate
38	BDL	-	-	-	-	-
44	BDL	-	BDL	9.14	-	BDL
58	BDL	-	BDL	-	-	BDL
61	BDL	-	BDL	-	-	BDL
80	BDL	-	BDL	BDL	-	BDL
90	BDL	-	BDL	BDL	-	BDL
99	BDL	-	BDL	-	BDL	BDL
110	-	-	-	BDL	-	-
122	BDL	-	BDL	-	-	BDL
134	BDL	BDL	BDL	BDL	BDL	BDL
141	-	-	-	BDL	-	-
147	BDL	BDL	BDL	BDL	-	BDL
155	BDL	BDL	BDL	BDL	BDL	BDL
165	BDL	BDL	BDL	-	BDL	BDL

"-" = Insufficient quantity for analysis
BDL = Below detection limit, Cr < 5 μg/l
[a] Samples were colleted from separate collection tanks
[b] EPA Standard = 5000 μg/l

Table J.4 Lead (Pb) concentration versus Time in surface runoff and leachate samples collected from the RAP and Limerock collection systems.

Time of Exposure (days)	Concentrations (μg/l) [b]					
	RAP Surface Runoff 1 [a]	RAP Surface Runoff 2 [a]	RAP Leachate	Limerock Surface Runoff 1 [a]	Limerock Surface Runoff 2 [a]	Limerock Leachate
38	38.39	-	-	-	-	-
44	BDL	-	BDL	8.5	-	BDL
58	BDL	-	7.76	-	-	BDL
61	334.76	-	BDL	-	-	6.35
80	BDL	-	BDL	BDL	-	BDL
90	BDL	-	BDL	BDL	-	BDL
99	BDL	-	BDL	-	BDL	BDL
110	-	-	-	BDL	-	-
122	BDL	-	BDL	-	-	BDL
134	BDL	BDL	BDL	BDL	BDL	BDL
141	-	-	-	BDL	-	-
147	BDL	BDL	BDL	6.41	-	5.71
155	BDL	BDL	BDL	6.52	BDL	BDL
165	20.77	BDL	BDL	-	BDL	BDL
179	BDL	BDL	BDL	8.80	-	BDL
197	BDL	BDL	BDL	8.77	-	BDL
290	BDL	BDL	BDL	BDL	-	BDL

"-" = Insufficient quantity for analysis
BDL = Below detection limit, Pb < 5 μg/l
[a] Samples were colleted from separate collection tanks
[b] EPA Standard = 5000 μg/l

Table J.5 Selenium (Se) concentration versus Time in surface runoff and leachate samples collected from the RAP and Limerock collection systems.

Time of Exposure (day)	Concentrations (μg/l)[b]					
	RAP Surface Runoff 1 [a]	RAP Surface Runoff 2 [a]	RAP Leachate	Limerock Surface Runoff 1 [a]	Limerock Surface Runoff 2 [a]	Limerock Leachate
38	1.79	-	-	-	-	-
44	2.55	-	85.00	50.22	-	11.44
58	BDL	-	2.77	-	-	57.46
61	BDL	-	9.36	-	-	24.72
80	BDL	-	3.92	38.04	-	65.96
90	1.13	-	2.42	30.54	-	1,026.80
99	1.55	-	1.28	-	15.22	1,061.60
110	-	-	-	18.66	-	-
122	1.23	-	BDL	-	-	967.60
134	BDL	4.32	2.53	14.49	12.95	412.00
141	-	-	-	16.79	-	-
147	BDL	3.26	1.73	14.79	-	434.15
155	BDL	BDL	1.06	7.79	6.36	526.60
165	BDL	2.52	4.54	-	6.64	103.55

"-" = represents not Insufficient quantity for analysis
BDL = Below detection limit, Se < 1 μg/l
[a] Samples were colleted from separate collection tanks
[b] EPA Standard = = 1000 μg/l

Table J.6 Concentration of cadmium (Cd) versus time from column leaching tests on RAP and limerock

Time (min)	Concentrations (μg/l) [a]		
	RAP DDW	RAP Acid Rain	Limerock DDW
0	BDL	12.89	BDL
120	BDL	7.63	BDL
180	BDL	3.29	BDL
240	BDL	1.52	BDL
300	BDL	BDL	BDL
360	BDL	BDL	BDL

BDL = Below detection limit, Cd < 1 μg/l

[a] EPA Standard-1000 μg/l

Table J.7 Concentration of lead (Pb) versus time from column leaching test on RAP and Limerock

Time (min)	Concentrations (μg/l)[a]		
	RAP DDW	RAP Acid Rain	Limerock DDW
0	BDL	BDL	BDL
120	BDL	BDL	112.96
180	BDL	BDL	6.92
240	BDL	BDL	BDL
300	BDL	BDL	BDL
360	BDL	BDL	BDL

BDL = Below detection limit, Pb < 5 μg/l l

[a] EPA Standard-5000 μg/l

Table J.8 Selenium (Se) concentration versus time from column leaching tests on RAP and Limerock

Time (min)	Concentrations (μg/l)[a]				
	RAP DDW1	RAP DDW2	RAP Acid Rain	Limerock DDW1	Limerock DDW2
0	BDL	BDL	BDL	BDL	BDL
120	1.31	BDL	BDL	1,949.00	1,843.50
180	BDL	BDL	BDL	1,867.00	1,890.00
240	BDL	1.29	BDL	1,668.50	1,833.00
300	BDL	BDL	BDL	1,462.50	1,735.00
360	1.26	1.03	BDL	1,191.00	1,499.00

BDL = Below detection limit, Se < 1 μg/l
[a] EPA Standard = 1000 μg/l

Appendix K

RAP-Soil Mixtures Resilient Modulus Data

Resilient Modulus Test Results

Foundations Laboratory - State Materials Office

Procedure: SHRP (P46) - Type 1

Lab # : 20889
Sample # : 1B
LBR :

Date: 25-Jun-02
Proj. NO.: FIT RAP Study

Material Discription: 100% RAP at 8% moisture
Comments: w_f = 6.9%

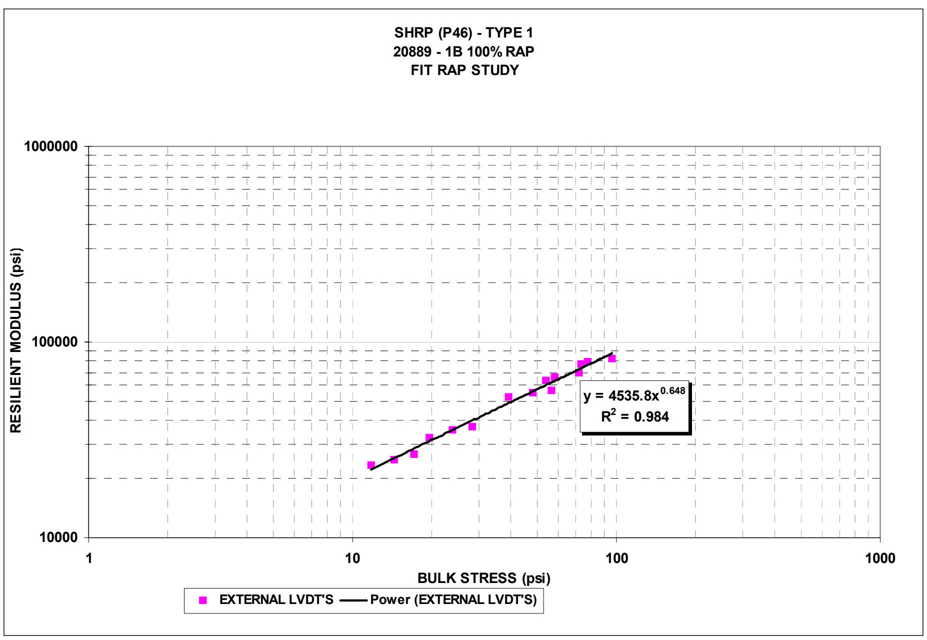
Soil Class :

Conditioning Information:
Repetitions = 500
σ Deviator = 15 psi
σ Confining = 15 psi

INSITU or TARGET MOIST. / DENSITY:
118 @ 8%
ACTUAL MOISTURE / DENSITY:
118.3 @ 7.8%

2 EXTERNAL LVDT'S

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	3	2.72	0.29	3.01	11.72	0.00092688	0.00011586	23440
2	3	5.46	0.56	6.01	14.46	0.00174603	0.00021825	24996
3	3	8.12	0.90	9.02	17.12	0.00243118	0.0003039	26709
4	5	4.50	0.51	5.01	19.50	0.00111691	0.00013961	32245
5	5	8.97	1.04	10.01	23.97	0.00201276	0.0002516	35649
6	5	13.49	1.52	15.01	28.49	0.00291465	0.00036433	37015
7	10	8.96	1.04	10.01	38.96	0.00136209	0.00017026	52640
8	10	18.03	1.98	20.01	48.03	0.00260828	0.00032603	55297
9	10	27.00	3.02	30.02	57.00	0.00379715	0.00047464	56887
10	15	9.02	0.99	10.01	54.02	0.0011307	0.00014134	63785
11	15	13.51	1.51	15.02	58.51	0.00162754	0.00020344	66414
12	15	27.02	2.98	30.01	72.02	0.00310684	0.00038835	69587
13	20	13.46	1.55	15.01	73.46	0.00139135	0.00017392	77382
14	20	18.04	1.96	20.00	78.04	0.00181369	0.00022671	79567
15	20	36.00	4.02	40.02	96.00	0.00351189	0.00043899	82000



Resilient Modulus Test Results

Foundations Laboratory - State Materials Office

Procedure: SHRP (P46) - Type 1

Lab # : 20889
Date: 25-Jun-02 Sample # : 1C
Proj. NO.: FIT RAP Study LBR :

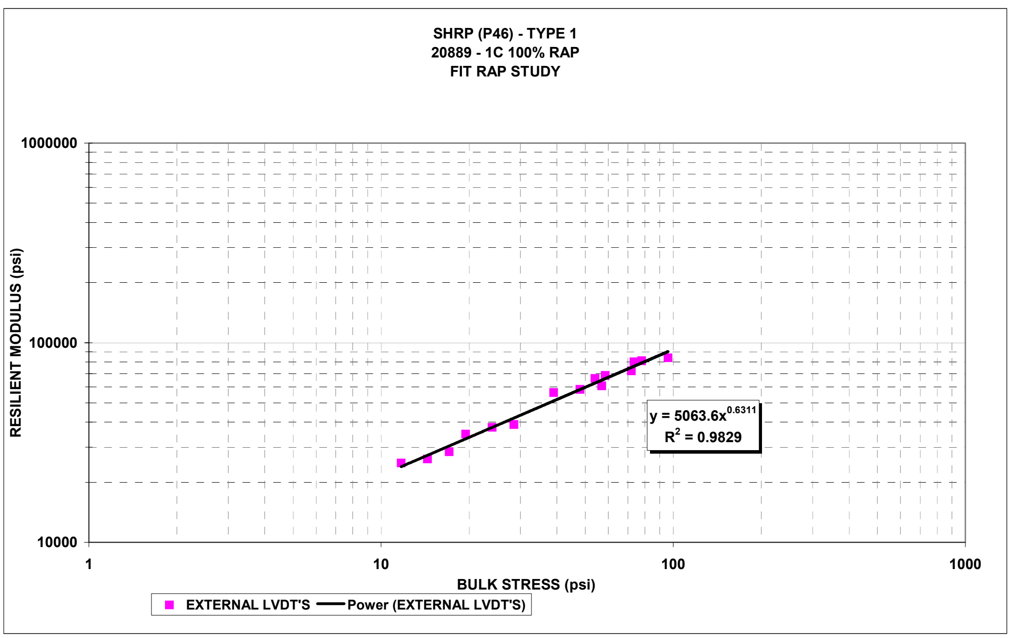
Material Discription: 100% RAP at 8% moisture
Comments: w_f =7.0% Soil Class :

Conditioning Information:
Repetitions = 500
σ Deviator = 15 psi
σ Confining = 15 psi

INSITU or TARGET MOIST. / DENSITY:
118 @ 8%
ACTUAL MOISTURE / DENSITY:
117.9 @ 8.3%

2 EXTERNAL LVDT'S

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	3	2.72	0.30	3.01	11.72	0.00087086	0.00010886	24971
2	3	5.42	0.60	6.01	14.42	0.00165770	0.00020721	26145
3	3	8.11	0.90	9.01	17.11	0.00228424	0.00028553	28419
4	5	4.49	0.53	5.01	19.49	0.00103073	0.00012884	34833
5	5	9.01	0.99	10.00	24.01	0.00191322	0.00023915	37690
6	5	13.52	1.49	15.01	28.52	0.00278322	0.00034790	38867
7	10	8.99	1.02	10.01	38.99	0.00127850	0.00015981	56252
8	10	18.02	1.99	20.00	48.02	0.00246780	0.00030848	58408
9	10	26.96	3.06	30.01	56.96	0.00354593	0.00044324	60814
10	15	9.02	0.99	10.01	54.02	0.00108890	0.00013611	66270
11	15	13.56	1.45	15.01	58.56	0.00158143	0.00019768	68583
12	15	26.99	3.02	30.01	71.99	0.00298489	0.00037311	72335
13	20	13.53	1.48	15.01	73.53	0.00135089	0.00016886	80127
14	20	18.03	1.98	20.01	78.03	0.00177577	0.00022197	81225
15	20	36.04	3.98	40.02	96.04	0.00343476	0.00042934	83939



Resilient Modulus Test Results

Foundations Laboratory - State Materials Office

Procedure: SHRP (P46) - Type 1

Lab # : 20889
Sample # : 2C
LBR :

Date: 27-Jun-02
Proj. NO.: FIT RAP Study

Material Discription: 80% RAP at 6% moisture
Comments: w_f = 6.8%

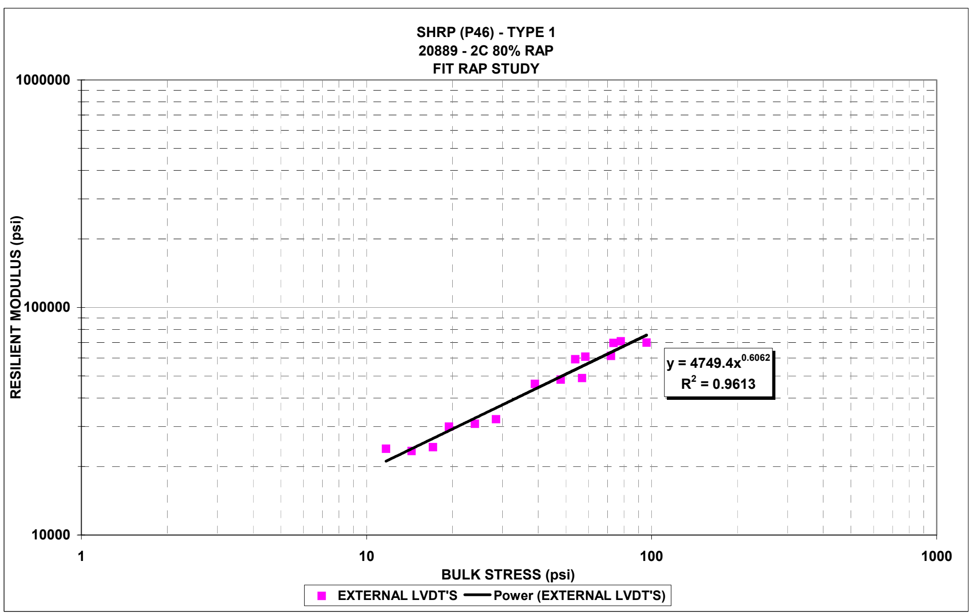
Soil Class :

Conditioning Information:
Repetitions = 500
σ Deviator = 15 psi
σ Confining = 15 psi

INSITU or TARGET MOIST. / DENSITY:
122 @ 6%
ACTUAL MOISTURE / DENSITY:
118.4 @ 6.3%

2 EXTERNAL LVDT'S

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	3	2.70	0.31	3.01	11.70	0.00090447	0.00011306	23919
2	3	5.39	0.62	6.01	14.39	0.00184127	0.00023016	23410
3	3	8.11	0.91	9.02	17.11	0.00267210	0.00033401	24295
4	5	4.48	0.53	5.01	19.48	0.00119921	0.00014990	29900
5	5	9.01	1.00	10.00	24.01	0.00234111	0.00029264	30776
6	5	13.49	1.51	15.00	28.49	0.00334858	0.00041857	32236
7	10	8.99	1.02	10.01	38.99	0.00155945	0.00019493	46139
8	10	18.04	1.97	20.01	48.04	0.00299566	0.00037446	48175
9	10	27.05	2.97	30.02	57.05	0.00442584	0.00055323	48893
10	15	9.01	0.99	10.00	54.01	0.00121860	0.00015233	59162
11	15	13.56	1.47	15.00	58.56	0.00178481	0.00022310	60650
12	15	27.02	3.00	30.02	72.02	0.00353128	0.00044141	61202
13	20	13.50	1.51	15.01	73.50	0.00154609	0.00019326	69840
14	20	18.02	2.01	20.03	78.02	0.00203244	0.00025406	70937
15	20	36.00	4.01	40.01	96.00	0.00411128	0.00051391	70053



Resilient Modulus Test Results

Foundations Laboratory - State Materials Office

Procedure: SHRP (P46) - Type 1

Lab # : 20889
Sample # : 2B
LBR :

Date: 25-Jun-02
Proj. NO.: FIT RAP Study

Material Discription: 80% RAP at 6% moisture
Comments: w_f = 6.8%

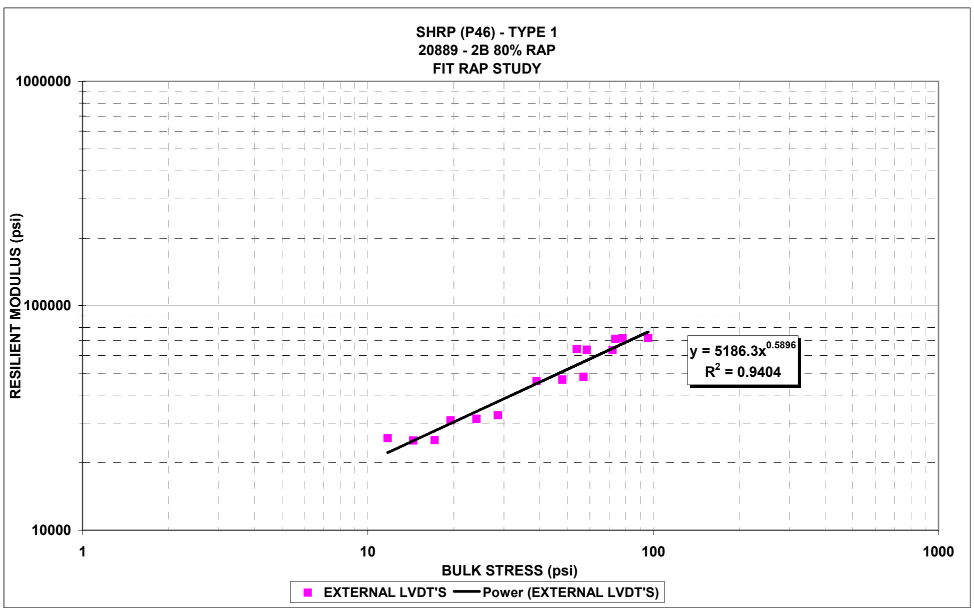
Soil Class :

Conditioning Information:
Repetitions = 500
σ Deviator = 15 psi
σ Confining = 15 psi

INSITU or TARGET MOIST. / DENSITY:
122 @ 6%
ACTUAL MOISTURE / DENSITY:
120.6 @ 6.3%

2 EXTERNAL LVDT'S

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	3	2.73	0.28	3.01	11.73	0.00085018	0.00010627	25725
2	3	5.42	0.59	6.01	14.42	0.00172923	0.00021615	25090
3	3	8.13	0.90	9.03	17.13	0.00257639	0.00032205	25237
4	5	4.50	0.51	5.02	19.50	0.00116690	0.00014586	30864
5	5	9.05	0.96	10.01	24.05	0.00230923	0.00028865	31343
6	5	13.56	1.44	15.01	28.56	0.00333564	0.00041696	32527
7	10	9.02	0.99	10.01	39.02	0.00156333	0.00019542	46171
8	10	18.07	1.95	20.02	48.07	0.00308314	0.00038539	46883
9	10	27.04	2.99	30.02	57.04	0.00448444	0.00056056	48229
10	15	8.95	1.06	10.01	53.95	0.00111562	0.00013945	64181
11	15	13.51	1.50	15.01	58.51	0.00169863	0.00021233	63649
12	15	27.05	2.97	30.02	72.05	0.00340674	0.00042584	63519
13	20	13.58	1.45	15.03	73.58	0.00152541	0.00019068	71233
14	20	18.09	1.93	20.02	78.09	0.00202052	0.00025256	71614
15	20	36.04	3.99	40.04	96.04	0.00400915	0.00050114	71921



Resilient Modulus Test Results

Foundations Laboratory - State Materials Office

Procedure: SHRP (P46) - Type 1

Lab # : 20889
Date: 28-Jun-02 Sample # : 3A
Proj. NO.: FIT RAP Study LBR :

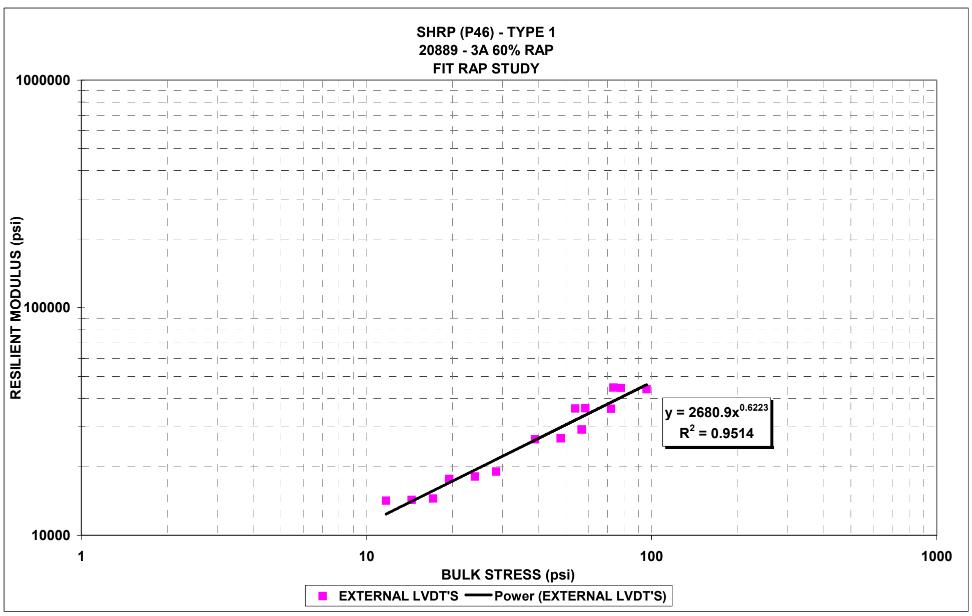
Material Discription: 60% RAP at 8% moisture
Comments: w_f = 8.8% Soil Class :

Conditioning Information:
Repetitions = 500
σ Deviator = 15 psi
σ Confining = 15 psi

INSITU or TARGET MOIST. / DENSITY:
121 @ 8%
ACTUAL MOISTURE / DENSITY:
116.1 @ 8.6%

2 EXTERNAL LVDT'S

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	3	2.71	0.30	3.01	11.71	0.00152670	0.00019084	14192
2	3	5.40	0.61	6.01	14.40	0.00301979	0.00037747	14304
3	3	8.13	0.89	9.02	17.13	0.00448228	0.00056029	14506
4	5	4.51	0.50	5.01	19.51	0.00203862	0.00025483	17705
5	5	9.00	1.01	10.01	24.00	0.00397382	0.00049673	18121
6	5	13.51	1.50	15.01	28.51	0.00567288	0.00070911	19054
7	10	8.98	1.03	10.01	38.98	0.00272376	0.00034047	26389
8	10	18.01	1.99	20.00	48.01	0.00540357	0.00067545	26669
9	10	26.85	3.20	30.05	56.85	0.00735700	0.00091963	29193
10	15	8.96	1.05	10.01	53.96	0.00198648	0.00024831	36091
11	15	13.53	1.48	15.01	58.53	0.00299479	0.00037435	36137
12	15	26.98	3.02	30.00	71.98	0.00599133	0.00074892	36030
13	20	13.48	1.52	15.00	73.48	0.00241954	0.00030244	44573
14	20	18.04	1.97	20.01	78.04	0.00324774	0.00040597	44440
15	20	36.05	3.98	40.03	96.05	0.00658597	0.00082325	43790



Resilient Modulus Test Results

Foundations Laboratory - State Materials Office

Procedure: SHRP (P46) - Type 1

Lab # : 20889
Sample # : 3B
LBR :

Date: 25-Jun-02
Proj. NO.: FIT RAP Study

Material Discription: 60% RAP at 8% moisture
Comments: w_f = 8.4%

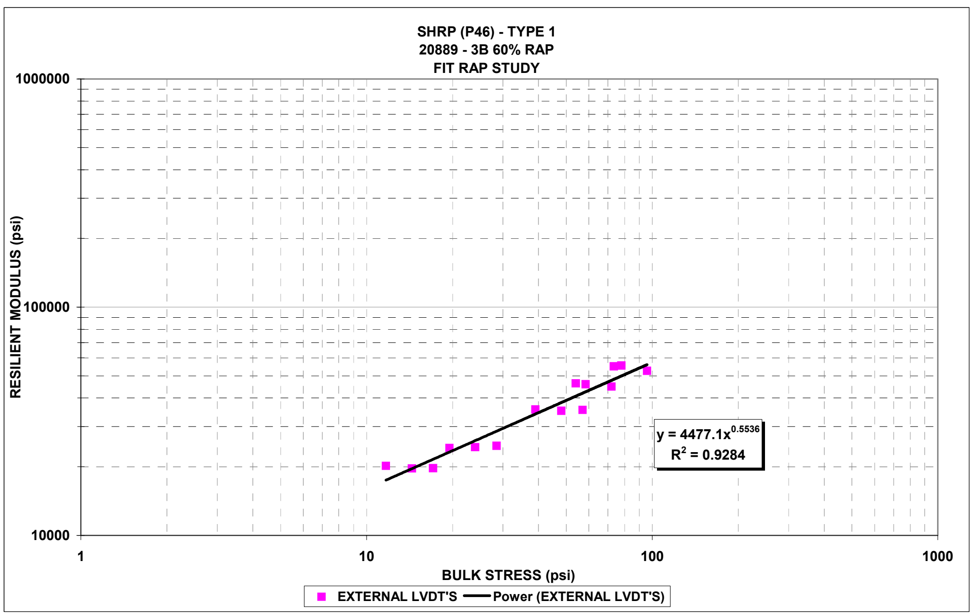
Soil Class :

Conditioning Information:
Repetitions = 500
σ Deviator = 15 psi
σ Confining = 15 psi

INSITU or TARGET MOIST. / DENSITY:
121 @ 8%
ACTUAL MOISTURE / DENSITY:
117.0 @ 8.4%

2 EXTERNAL LVDT'S

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	3	2.69	0.32	3.01	11.69	0.00106693	0.00013337	20190
2	3	5.42	0.59	6.01	14.42	0.00220452	0.00027556	19669
3	3	8.10	0.92	9.02	17.10	0.00328652	0.00041082	19710
4	5	4.51	0.51	5.02	19.51	0.00149352	0.00018669	24136
5	5	8.99	1.02	10.01	23.99	0.00294912	0.00036864	24375
6	5	13.52	1.48	15.00	28.52	0.00437844	0.00054730	24708
7	10	9.02	0.99	10.01	39.02	0.00202655	0.00025332	35588
8	10	18.05	1.96	20.01	48.05	0.00410180	0.00051272	35195
9	10	27.05	2.96	30.01	57.05	0.00610034	0.00076254	35472
10	15	9.03	0.98	10.01	54.03	0.00155600	0.00019450	46402
11	15	13.50	1.51	15.01	58.50	0.00234887	0.00029361	45973
12	15	27.03	2.98	30.01	72.03	0.00481581	0.00060198	44908
13	20	13.48	1.53	15.01	73.48	0.00195760	0.00024470	55085
14	20	18.01	2.00	20.01	78.01	0.00259276	0.00032410	55562
15	20	35.98	4.03	40.01	95.98	0.00547294	0.00068412	52595



RESILIENT MODULUS TEST RESULTS

FOUNDATIONS LABORATORY - STATE MATERIALS OFFICE

PROCEDURE: SHRP (P46) - TYPE II

LAB #: 20889

DATE: July 11, 2002

SAMPLE #: 1A

PROJ. NO.:

LBR:

MATERIAL DESCRIPTION: 100% RAP

COMMENTS:

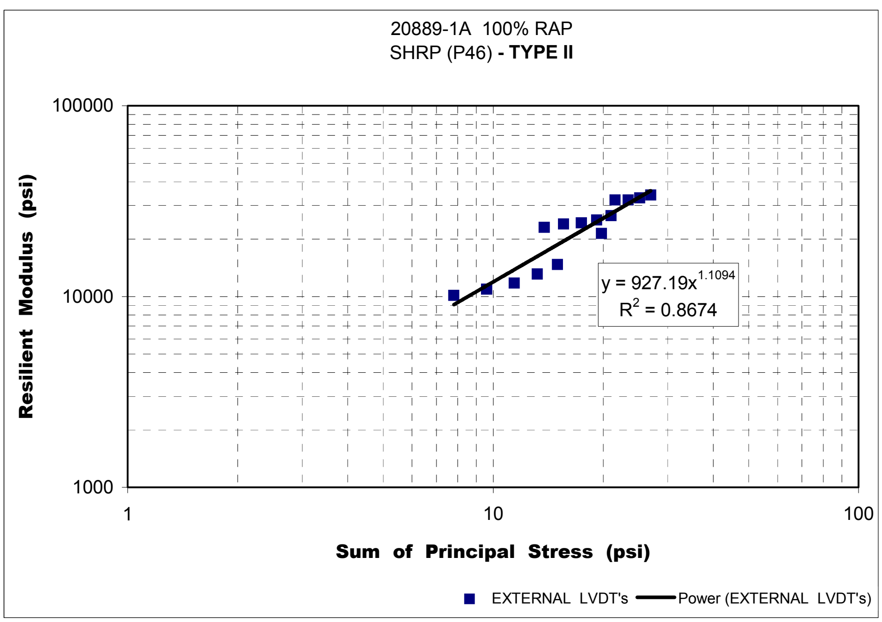
SOIL CLASS:

CONDITIONING INFORMATION:
REPETITIONS = 500
σ DEVIATOR = 15 psi
σ CONFINING = 15 psi

INSITU or TARGET MOIST. / DENSITY:
118 @ 8%
ACTUAL MOISTURE / DENSITY:
117.7 @ 7.7%

2 EXTERNAL LVDT's

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	6	1.80	0.21	2.00	19.80	0.00067113	0.00008389	21436
2	6	3.59	0.42	4.00	21.59	0.00089370	0.00011171	32111
3	6	5.44	0.57	6.01	23.44	0.00135649	0.00016956	32073
4	6	7.19	0.80	7.99	25.19	0.00175139	0.00021892	32864
5	6	8.97	1.03	10.00	26.97	0.00210541	0.00026318	34098
6	4	1.81	0.19	2.00	13.81	0.00062858	0.00007857	23043
7	4	3.60	0.41	4.01	15.60	0.00119792	0.00014974	24018
8	4	5.44	0.57	6.01	17.44	0.00178525	0.00022316	24357
9	4	7.20	0.81	8.01	19.20	0.00228682	0.00028585	25201
10	4	9.02	0.99	10.00	21.02	0.00272204	0.00034025	26504
11	2	1.81	0.20	2.00	7.81	0.00142931	0.00017866	10125
12	2	3.61	0.40	4.01	9.61	0.00264275	0.00033034	10927
13	2	5.43	0.58	6.01	11.43	0.00369287	0.00046161	11761
14	2	7.21	0.80	8.01	13.21	0.00439826	0.00054978	13111
15	2	9.01	0.99	10.00	15.01	0.00490544	0.00061318	14694



RESILIENT MODULUS TEST RESULTS

FOUNDATIONS LABORATORY - STATE MATERIALS OFFICE

PROCEDURE : SHRP (P46) - TYPE II

LAB # : 20889
SAMPLE # : 1D
LBR :

DATE: July 19, 2002
PROJ. NO.: FIT RAP STUDY
MATERIAL DESCRIPTION : 100% RAP
COMMENTS :

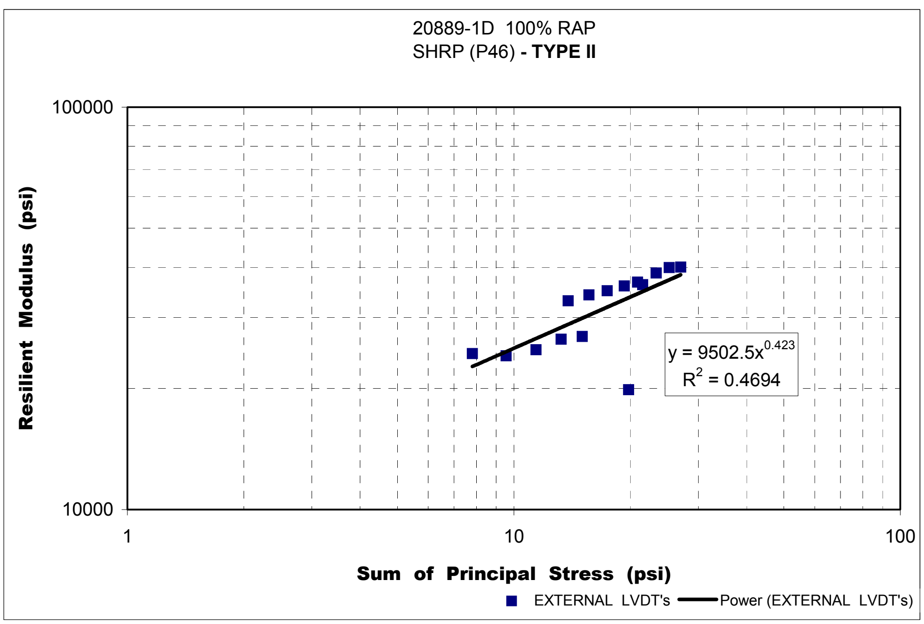
SOIL CLASS :

CONDITIONING INFORMATION:
REPETITIONS = 500
σ DEVIATOR = 15 psi
σ CONFINING = 15 psi

INSITU or TARGET MOIST. / DENSITY:
118 @ 8%
ACTUAL MOISTURE / DENSITY:
116.6 @ 8.4%

2 EXTERNAL LVDT's

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	6	1.82	0.21	2.03	19.82	0.00073384	0.00009173	19846
2	6	3.57	0.44	4.00	21.57	0.00078813	0.00009852	36197
3	6	5.37	0.62	5.99	23.37	0.00111002	0.00013875	38717
4	6	7.24	0.74	7.98	25.24	0.00145000	0.00018125	39943
5	6	9.04	1.01	10.05	27.04	0.00180550	0.00022569	40061
6	4	1.81	0.20	2.01	13.81	0.00043866	0.00005483	33034
7	4	3.64	0.37	4.01	15.64	0.00085362	0.00010670	34124
8	4	5.44	0.57	6.01	17.44	0.00124489	0.00015561	34977
9	4	7.33	0.68	8.01	19.33	0.00163012	0.00020376	35950
10	4	8.90	1.11	10.01	20.90	0.00193785	0.00024223	36753
11	2	1.81	0.19	2.00	7.81	0.00059411	0.00007426	24409
12	2	3.55	0.46	4.01	9.55	0.00117982	0.00014748	24086
13	2	5.42	0.57	5.99	11.42	0.00173655	0.00021707	24955
14	2	7.26	0.75	8.01	13.26	0.00219288	0.00027411	26490
15	2	9.04	0.97	10.01	15.04	0.00268541	0.00033568	26927



RESILIENT MODULUS TEST RESULTS

FOUNDATIONS LABORATORY - STATE MATERIALS OFFICE

PROCEDURE : SHRP (P46) - TYPE II

LAB # : 20889

DATE: July 9, 2002

SAMPLE # : 2A

PROJ. NO.:

LBR :

MATERIAL DESCRIPTION : 80% RAP

COMMENTS :

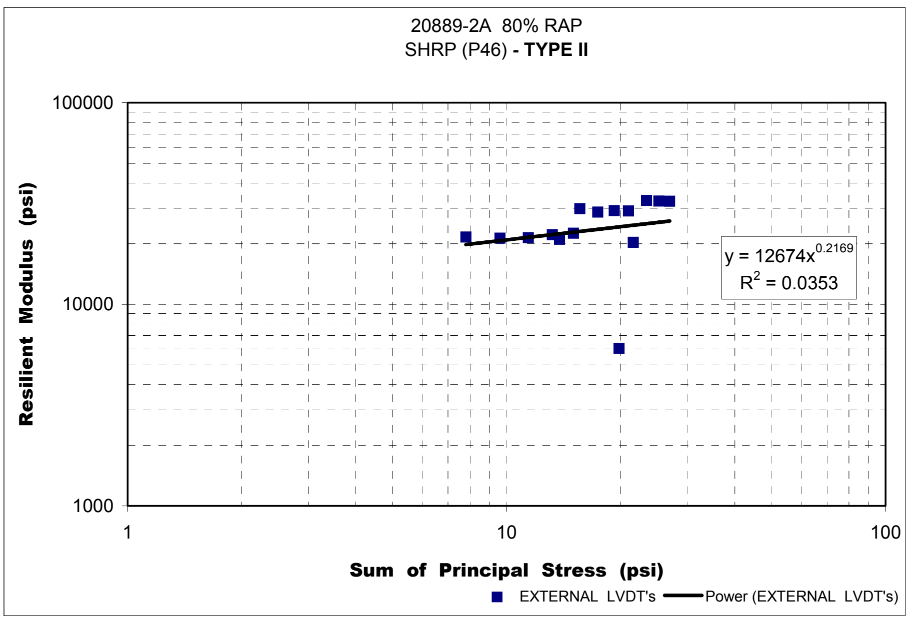
SOIL CLASS :

CONDITIONING INFORMATION:
REPETITIONS = 500
σ DEVIATOR = 15 psi
σ CONFINING = 15 psi

INSITU or TARGET MOIST. / DENSITY:
122 @ 6%
ACTUAL MOISTURE / DENSITY:
119.2 @ 6.0%

2 EXTERNAL LVDT's

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	6	1.80	0.20	2.00	19.80	0.00238981	0.00029873	6038
2	6	3.60	0.42	4.01	21.60	0.00141682	0.00017710	20300
3	6	5.41	0.60	6.01	23.41	0.00132073	0.00016509	32750
4	6	7.22	0.80	8.01	25.22	0.00177404	0.00022176	32536
5	6	8.94	1.06	10.01	26.94	0.00220711	0.00027589	32412
6	4	1.81	0.20	2.01	13.81	0.00068802	0.00008600	21020
7	4	3.60	0.41	4.01	15.60	0.00096653	0.00012082	29801
8	4	5.41	0.60	6.01	17.41	0.00150688	0.00018836	28713
9	4	7.22	0.79	8.01	19.22	0.00198121	0.00024765	29159
10	4	8.98	1.02	10.00	20.98	0.00247082	0.00030885	29073
11	2	1.81	0.20	2.01	7.81	0.00066920	0.00008365	21605
12	2	3.61	0.40	4.01	9.61	0.00135822	0.00016978	21284
13	2	5.41	0.60	6.01	11.41	0.00202311	0.00025289	21384
14	2	7.21	0.80	8.01	13.21	0.00260310	0.00032539	22159
15	2	9.03	0.97	10.00	15.03	0.00320293	0.00040037	22548



RESILIENT MODULUS TEST RESULTS

FOUNDATIONS LABORATORY - STATE MATERIALS OFFICE

PROCEDURE : SHRP (P46) - TYPE II

LAB # : 20889
SAMPLE # : 2D
LBR :
SOIL CLASS :

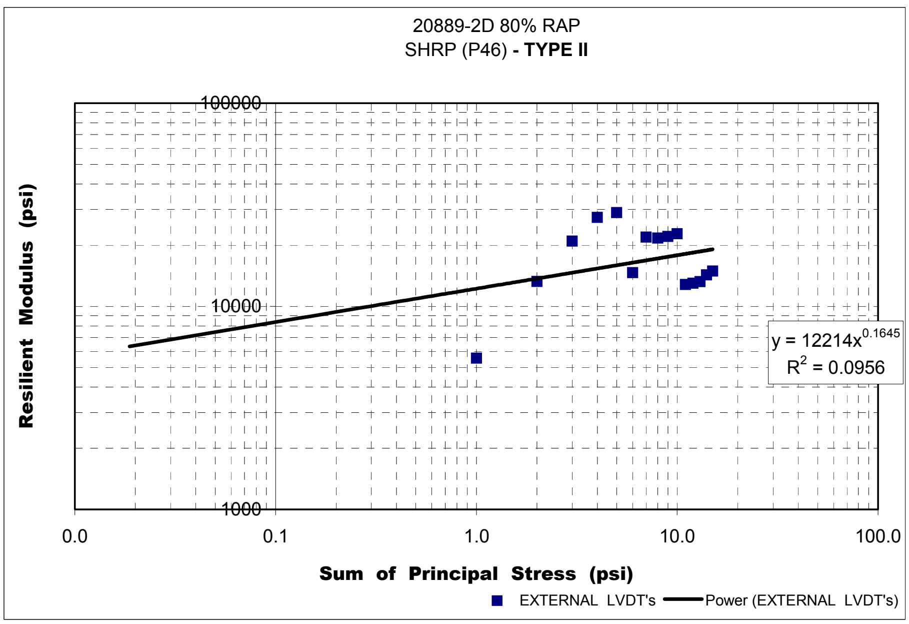
DATE: July 18, 2002
PROJ. NO.: FIT RAP STUDY
MATERIAL DESCRIPTION : 80% RAP
COMMENTS :

CONDITIONING INFORMATION:
REPETITIONS = 500
σ DEVIATOR = 15 psi
σ CONFINING = 15 psi

INSITU or TARGET MOIST. / DENSI
122 @ 6%
ACTUAL MOISTURE / DENSITY:
119.9 @ 6.8%

2 EXTERNAL LVDT's

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	6	1.81	0.19	2.00	19.81	0.00260513	0.00032564	5555
2	6	3.58	0.43	4.01	21.58	0.00216267	0.00027033	13240
3	6	5.46	0.57	6.02	23.46	0.00208750	0.00026094	20917
4	6	7.31	0.71	8.01	25.31	0.00213514	0.00026689	27384
5	6	8.91	1.10	10.01	26.91	0.00246392	0.00030799	28917
6	4	1.80	0.20	2.00	13.80	0.00098438	0.00012305	14635
7	4	3.64	0.37	4.01	15.64	0.00132978	0.00016622	21912
8	4	5.33	0.69	6.01	17.33	0.00196580	0.00024572	21675
9	4	7.08	0.93	8.01	19.08	0.00256864	0.00032108	22057
10	4	9.02	0.99	10.00	21.02	0.00317319	0.00039665	22729
11	2	1.79	0.21	2.01	7.79	0.00112381	0.00014048	12776
12	2	3.58	0.43	4.01	9.58	0.00220796	0.00027600	12969
13	2	5.45	0.57	6.01	11.45	0.00329471	0.00041184	13225
14	2	7.25	0.77	8.01	13.25	0.00406431	0.00050804	14266
15	2	9.02	0.98	10.00	15.02	0.00484942	0.00060618	14887



RESILIENT MODULUS TEST RESULTS

FOUNDATIONS LABORATORY - STATE MATERIALS OFFICE

PROCEDURE : SHRP (P46) - TYPE II

DATE: July 18, 2002

PROJ. NO.: FIT RAP STUDY

MATERIAL DESCRIPTION : 60% RAP

COMMENTS :

LAB # : 20889

SAMPLE # : 3C

LBR :

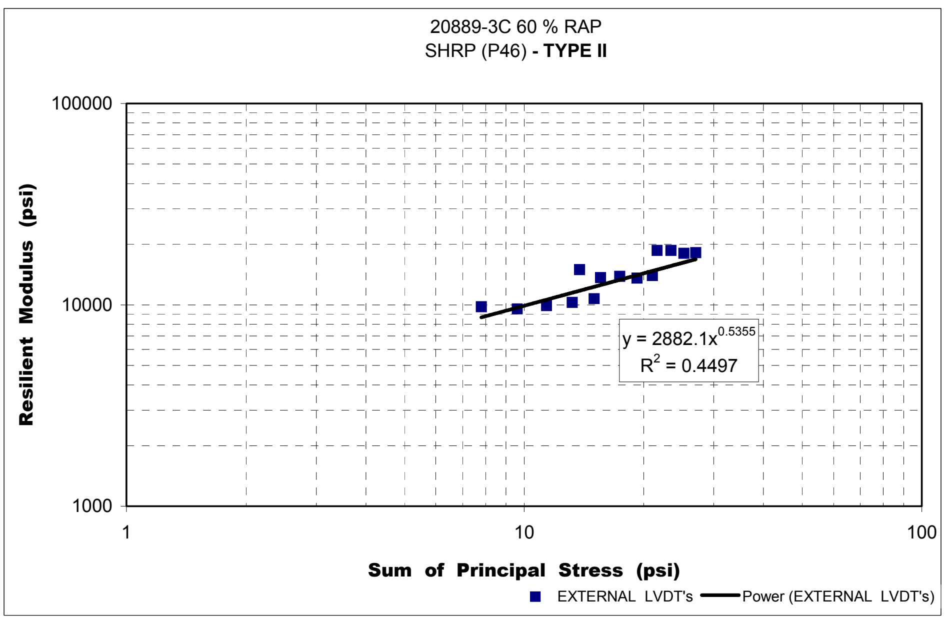
SOIL CLASS :

CONDITIONING INFORMATION:
REPETITIONS = 500
σ DEVIATOR = 15 psi
σ CONFINING = 15 psi

INSITU or TARGET MOIST. / DENSITY
121 @ 8%
ACTUAL MOISTURE / DENSITY:
116.4 @ 9.1%

2 EXTERNAL LVDT's

TEST SEQ. #	CONFINING STRESS (psi)	CYCLIC STRESS (psi)	CONTACT STRESS (psi)	MAX. AXIAL STRESS (psi)	BULK STRESS (psi)	RESILIENT DEFORMATION (in)	RESILIENT STRAIN (in/in)	RESILIENT MODULUS (psi)
1	6	1.82	0.19	2.00	19.82	0.00194865	0.00024358	7452
2	6	3.61	0.40	4.00	21.61	0.00154954	0.00019369	18630
3	6	5.42	0.60	6.01	23.42	0.00232690	0.00029086	18619
4	6	7.23	0.78	8.01	25.23	0.00320724	0.00040091	18034
5	6	9.03	0.97	10.00	27.03	0.00397985	0.00049748	18141
6	4	1.79	0.21	2.00	13.79	0.00095963	0.00011995	14943
7	4	3.58	0.43	4.01	15.58	0.00209722	0.00026215	13646
8	4	5.40	0.61	6.01	17.40	0.00311976	0.00038997	13849
9	4	7.23	0.78	8.01	19.23	0.00425649	0.00053206	13586
10	4	9.02	1.02	10.03	21.02	0.00516321	0.00064540	13969
11	2	1.81	0.19	2.00	7.81	0.00147974	0.00018497	9788
12	2	3.61	0.40	4.01	9.61	0.00302927	0.00037866	9540
13	2	5.38	0.63	6.01	11.38	0.00434871	0.00054359	9903
14	2	7.22	0.79	8.01	13.22	0.00562204	0.00070275	10274
15	2	9.00	1.00	10.00	15.00	0.00670103	0.00083763	10740



Appendix L

Compaction Summary of RAP-Soil Mixtures

Compaction Characteristics of RAP-Soil Mixtures

Test		100% RAP ω (%)	100% RAP γ (lb/ft^3)	80% RAP ω (%)	80% RAP γ (lb/ft^3)	60% RAP ω (%)	60% RAP γ (lb/ft^3)	Mold size diameter (in)	Mold size volume (ft^3)
Moisture - Density		8.0	117.8	6.0	121.7	7.8	121.2	6	0.0750
	C.E. (ft-lb/ft^3)	56,000		56,000		56,000			
LBR - BASE	ave.	7.8	117.6	6.0	121.9	8.0	119.7	6	0.0750
	stdv.	0.43	0.75	0.08	0.77	0.17	1.49		
	C.E. (ft-lb/ft^3)	56,000		56,000		56,000			
	R.C	99.8%		100.2%		98.8%			
LBR - SUBGRADE	ave.	8.0	117.7	6.4	121.7	8.0	119.1	6	0.0750
	stdv.	0.33	0.26	0.70	1.87	0.31	2.02		
	C.E. (ft-lb/ft^3)	56,000		56,000		56,000			
	R.C	99.9%		100.0%		98.3%			
Static Triaxial Compression	ave.	7.8	119.8	6.0	123.7	8.6	118.0	4	0.0609
	stdv.	0.11	0.15	0.60	0.30	0.10	0.27		
	C.E. (ft-lb/ft^3)	56,153		56,153		56,153			
	R.C	101.7%		101.6%		97.4%			
Resilient Modulus BASE	ave.	8.1	118.1	6.3	119.5	8.5	116.6	4	0.0582
	stdv.	0.35	0.28	0.00	1.56	0.14	0.64		
	C.E. (ft-lb/ft^3)	58,785		58,785		58,785			
	R.C	100.3%		98.2%		96.2%			
Resilient Modulus SUBGRADE	ave.	8.1	117.2	6.4	119.6	9.1	116.4	4	0.0582
	stdv.	0.49	0.78	0.57	0.49	-	-		
	C.E. (ft-lb/ft^3)	58,785		58,785		58,785			
	R.C	99.5%		98.3%		96.0%			
Permeability	ave.	7.4	120.5	6.1	122.3	7.9	114.9	4	0.0317[a]
	stdv.	0.97	0.46	0.16	1.10	0.14	0.60		0.0333[b]
	C.E. (ft-lb/ft^3)	56,702		56,246		56,246			
	R.C (%)	102.3%		100.5%		94.8%			

ω : moisture content
γ : unit weight
C.E. : compactive effort
R.C. : relative compaction
[a] : volume of mold for 100% RAP samples
[b] : volume of mold for 80 and 60% RAP samples